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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 63, PP. 435–484 MAY 1952

BIOGEOCHEMICAL INVESTIGATIONS IN THE PACIFIC NORTHWEST

BY HARRY V. WARREN, ROBERT E. DELAVAULT, AND RUTH I. IRISH

ABSTRACT

Copper and zinc are so widespread in soils and vegetation that any attempt to apply biogeochemistry in search for buried ore bodies of these metals necessitates an accurate knowledge of the distribution of these elements in the absence of mineralization.

In this paper normal and abnormal, or anomalous, contents of copper and zinc in different organs of various ages have been determined and tabulated for the more common trees and lesser plants of the Pacific Northwest.

Some ways by which biogeochemical data may be used are described, including a brief discussion of statistical diagrams and profiles. Some common errors are discussed. Two sets of diagrams illustrating successful applications of biogeochemical data are also given.

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INTRODUCTION

Leyton (1948) has pointed out that when a tree retains more than one year's foliage there may be differences in composition not only between the various organs of that tree but also between the same organs of varying age.

As we have stated (Warren, Delavault, and Irish, 1949) it is most desirable to follow one technique throughout any one investigation. Unfortunately this is a counsel of perfection which it is not always practical to adopt. Most biogeochemists have a field season extending into months, and a technique applicable in May will usually be inappropriate in July. If biogeochemistry is to progress as a tool in the

search for hidden ore bodies it must be developed to the point where an investigator can move into a new area and, after sizing up the general geography and geology of that area, decide on the type of field work most likely to yield profitable results. The problem of choosing an appropriate field method is, in our opinion, most important; on it may depend the success or failure of the whole investigation.

To those who have not carried out biogeochemical investigations, some of the details discussed may sound involved. We think they are neither more nor less involved than any controversy concerning the selection of an appropriate method for a geophysical examination. Most geophysicists agree that the selection of an inappropriate geophysical method greatly lessens the chances of success in any investigation. To enable a biogeochemist to choose intelligently the methods which will best serve his needs, it would seem wise to explore as many biogeochemical techniques as possible, to compare their strong and weak points. We are satisfied that some of the indifferent results obtained by early workers were due to the use of inappropriate techniques rather than to any weakness in biogeochemistry as a tool. Any geophysicist knows that a gravimetric survey might be doomed to failure if used where a self-potential survey might produce useful results. Similarly the use of spruce buds where Douglas Fir twigs were available could, under some circumstances, vitiate a biogeochemical survey. The collecting of willow or alder leaves close to a lake shore when Devil's Club stems are available a short distance away might ruin an investigation.

By making available some of our results from the past five field seasons, and pointing out some of the pitfalls into which we have fallen, we hope we may hasten the development of biogeochemical techniques. We have obtained some results we cannot satisfactorily explain. We are presenting a few of these contradictory results in the hope that others may be able to provide the explanation.

Lastly we present a few by-products of our investigations and suggest a few new lines of promising research.

ACKNOWLEDGMENTS

The authors must emphasize above all their indebtedness to The Geological Society of America for various grants, commencing in 1946, from the Penrose Bequest. These grants have made this research possible. Less substantial but extremely welcome support has come from the University of British Columbia President's Committee on Research.

Many of our colleagues have assisted in various ways. Professors J. Davidson, T. M. C. Taylor, and D. J. Wort of the Department of Biology and Botany; Professor A. M. Crooker of the Department of Physics; Professors D. G. Laird, V. C. Brink, and C. A. Rowles of the Department of Agronomy; and Professor B. G. Griffith of the Faculty of Forestry, all of the University of British Columbia, have been particularly helpful.

During the past few years the following mining companies have co-operated either by permitting us to publish the results of research on their claims or by financing our researches and permitting us to publish many of the results: Consolidated Mining and Smelting Co. Ltd., Britannia Mining and Smelting Co. Ltd., Highland-Bell Ltd., Pioneer Gold Mines of B. C. Ltd., The Granby Consolidated Mining, Smelting and Power Co. Ltd., Kelowna Exploration Co. Ltd., New Jersey Zinc Explorations Ltd., and the British Columbia International Engineering Co. Ltd.

Several individuals were particularly gracious and helpful, and particular mention must be made of Professor M. Y. Williams, the Late Dean Daniel Buchanan, Dr. Alex. Smith, and Dr. J. Rousseau. Many of our friends acted as collectors, and to them we gladly acknowledge our indebtedness.

The botanical terms used are largely taken from *Native trees of Canada*, Bulletin 61, Fourth Edition, Ottawa, published by the Dominion Forest Service of Canada. A few of the lesser plants are taken from *A pocket guide to the trees and shrubs of British Columbia* by B. G. Griffith for the British Columbia Department of Lands, Victoria, B. C. These sources were considered eminently reliable, and they are usually more likely to be available to biogeochemists and geologists in the field than the *Index Kewensis*.

Collecting Problems

Leyton (1948) has pointed out that the time of day when the sample is taken may affect the mineral composition of a sample. In practice we have not found any evidence to suggest that such variations are great enough to interfere with biogeochemistry where applied to prospecting for zinc or copper. Detailed investigations may necessitate reconsideration of this problem.

Another aspect which probably merits more attention is the direction and grade of the slope on which a survey is being made. In many areas the vegetation on north and south slopes varies markedly. Limited resources have prevented our tackling this problem, other than empirically. However, we have discovered anomalies on both north and south slopes. In reconnaissance work our chief interest in this problem has been to try to find a widespread species which could be found growing in critical areas.

The age of a tree scarcely affects the mineral content of young organs. Furthermore this problem usually solves itself: one must take the available trees, and our experience, well supported by results, suggests that it is better to use one species of tree of varying age than to mix species in an effort to get trees of comparable age. We have not found substantial differences between high and low branches.

If we are permitted to bypass for the present the above problems, our survey is reduced to manageable proportions. Our present survey therefore consists of a report on the merits, as tools in biogeochemistry, of different species of trees, and their variously aged organs.

Notes on Analytical Problems

The analytical methods employed were essentially those described in a previous paper (Warren and Delavault, 1949, p. 539–540). Experience has given us a greater measure of confidence in the efficacy of this method and indicates that a precision of 2 to 5 per cent may be expected if enough copper is present in the sample. This precision is better than that likely to be obtained from any normal sampling technique. We no longer find it necessary to run controls using classical methods on a micro scale. The following points may be helpful to any who may wish to adopt the techniques we have used.

(a) Size of sample. In most cases the minimum amount of metal to be expected in a sample is known. The weight of sample to be used in an analysis should be such that it should contain a minimum of 5 γ of copper, and the aliquot carrying the zinc, or the whole sample if zinc only is needed, must contain at least 2 γ of zinc. This usually necessitates a 2-gram sample for copper and zinc and a decigram sample if zinc only is to be determined.

(b) Ashing. Most of our ashing was done in an automatically controlled electric oven at 620°C. We agree with those who state that losses may occur during ashing, but these losses seem to depend upon factors other than the temperatures finally reached. Possibly the main point is to prevent the sample from catching fire; the initial temperature of the oven should be low enough and the rise in temperature slow enough to prevent this. In the field a small gasoline stove, such as the Coleman stove used by the U. S. Geological Survey, gives good results. However, if such a stove is used care should be taken to distill off all volatile material, using a lid on the crucible if necessary, before raising the temperature to a red heat.

(c) Treatment of ash. The ash is transferred to a small beaker, preferably 20 ml., where it is moistened with a few drops of water and then attacked with about 1 ml. of 3 Normal hydrochloric acid for each gram of sample. By evaporating slowly to dryness in 10 to 20 minutes the metals are dissolved and oxidizing compounds destroyed. The beaker is then removed from heat, about 0.2 ml. of 3N hydrochloric acid added, next a few ml. of water, and, after a few minutes, the solution is passed into a graduated 50-ml. cylinder having a ground glass stopper, and there made up to a known volume, usually 10 ml., and titrated as indicated in the previous paper. The zinc may be titrated on an aliquot. However, we now prefer as a buffer a solution containing 250 grams of sodium acetate and 10 ml. of acetic acid per liter in place of the 10 per cent acetate solution previously recommended. If no cop-

per determination is needed, the copper in the solution can be complexed by adding a 50% sodium thiosulphate solution—about 10% of the total volume—after which only zinc can react on the dithizone solution.

(d) Unburnt material. Unburnt material can lead to low results because of a loss of the metal occluded in it. Furthermore, charcoal can be a powerful oxidizing catalyzer and can change dithizone into a yellow compound which cannot compensate the color of the red metal complex. More dithizone than is needed is used, and the final mixed color is not neutral gray but yellowish gray or even chocolate brown. Consequently it is wise to filter off any appreciable amount of charred material. The best ashless filter papers contain copper in appreciable amounts, and just before use they should be treated with Normal hydrochloric acid which is washed off with pure water. This treatment makes the filter brittle and consequently it cannot be given in advance.

(e) Ferric iron. Very large amounts of ferric iron, 1 milligram per ml. or more, may, even in acid solutions, cause oxidization of dithizone. Should vanadium be present even less ferric iron can prove troublesome. This trouble can be mitigated by a judicious use of hydroxylamine salts, or by removing the ferric iron with ether.

(f) Pure water. In the field clear natural water is usually purer, as far as heavy metals are concerned, than water distilled in the laboratory.

(g) An alternative method for copper determination. Frère Sylvestre C.S.C. (1942) has described for copper analyses a method which is more involved but which is better adapted to untrained workers.

General Remarks Concerning Tables

In the tables in this paper the term "negative" refers to an area where bedrock is well exposed and mineralization of the element being investigated is not present. "Positive" indicates that mineralization of the element occurs near by, although this mineralization may not be commercially significant.

Copper and zinc are expressed both as p.p.m. (parts per million) of dry-plant material, and in some tables as p.p.m. of ash; the latter figure is bracketed. The p.p.m. in ash figure is in many instances determined directly from the absolute amounts of copper and zinc extracted from the sample during the making of the analyses. This method of calculation and the fact that the number of significant figures is everywhere reduced to a minimum may make some slight discrepancies apparent to those who examine the tables closely. However, it is believed that the results as presented are in no case distorted with respect to the general principles being evaluated.

In a previous paper (Warren and Delavault, 1948) we discussed our reason for not studying wood, bark, or cones.

A. The Gymnospermae

Family Pinaceae

The Gymnospermae as a group have many features to commend them for biogeochemical work in the Pacific Northwest. There are few areas where one or more genera are not present, and their identification, except possibly for some species of spruce, is comparatively simple. Our data suggest that, even if a species is wrongly identified, no harm will be done, provided the genus is determined correctly.

The Gymnospermae may be determined in winter as well as in summer. This may make it possible in some areas to carry on biogeochemical work even where there is deep snow on the ground.

Our work has dealt only with Pinaceae, but we have found that the genera of this family we have investigated differ significantly in the trace-element contents of their variously aged organs.

A consideration of the copper and zinc content of the tips, stems, and needles of the species which we have investigated follows:

Genus *Pseudotsuga*

Pseudotsuga taxifolia (Poiret) Britton (Douglas Fir)

We have not attempted to distinguish this species from the subspecies or variety *glauca* (Mayr) Sudworth.

The Douglas Fir is also known locally as British Columbia Fir, red fir, yellow fir, Doug-

las spruce, Douglas pine, Oregon pine, and Oregon spruce. The variety *glauca* is sometimes called Blue Douglas Fir and is more rarely referred to as Mountain Douglas Fir and Rocky Mountain Douglas Fir.

Douglas Fir is one of the most useful species of trees for biogeochemical investigations in the Pacific Northwest. It is widespread in southern Alberta and British Columbia, in Montana, Idaho, Washington, and Oregon. It grows close to Juniper and Sagebrush on the one hand and in proximity to Cedar and Hemlock on the other. We have found it at elevations of 6000 feet in southern British Columbia, and even here its copper and zinc content appeared comparable with that of specimens growing close to tide water.

Douglas Fir is readily identifiable wherever cones are available because of their conspicuous three-forked bracts.

For these reasons we have paid special attention to this species. In many instances it is convenient to use it as a yard stick in discussing other species.

Fortunately needles and stems are readily separated in Douglas Fir. If the specimen be allowed to dry the needles fall off naturally. However, if field analyses are being made and "green" or undried samples are being run, needles can easily be stripped from a stem.

In general stems of one full year's growth are preferred where Douglas Fir is being used for biogeochemical investigations.

However, the ease of collecting, as opposed to the ease of analyzing, may tip the scales in favor of buds when the collecting is being done by several people of varying degrees of competence. A high-school child can be taught to collect buds effectively. A lazy or indifferent adult can be expected to mix second- and third-year stems. By merely glancing at a bag of buds it is possible to size up whether or not the collection is satisfactory. It is relatively easy to overlook an appreciable amount of older stems in a collection of second-year material.

One key point arises from the evidence presented in Tables 1, 2, and 3. Heavy mineralization—Sample No. 48.47—could be detected biogeochemically whatever organ or whatever aged material was collected. Weak mineralization—Sample No. 48.37—produces anomalies comparable with the variations found when various organs are compared. In other words it is possible to detect major anomalies using almost any method of collecting and analyzing, but minor anomalies, such as those which are liable to be of importance in tracing down most buried ore bodies, can be found only by careful collecting and attention to details.

In Table 1 the copper, zinc, and ash content of needles and stems are compared.

These samples were collected from trees growing in widely differing climatic zones and over widely differing country rock. Although the ash content of Douglas Fir stems is normally lower than that of the needles growing on them, the copper and zinc content of the stems is almost twice that of the needles. The lower ash content of the stems relative to the needles causes these differences to be even more marked in the ash than it is in the dry plant material.

Because the needles contain much less copper and zinc than the stems it is good practice to select stems for analytical work: this we prefer to do with this species.

In the early part of the growing season a collector is tempted to take young Douglas Fir tips or buds. They readily break off from the growth of the previous season and can be plucked easily by thumb and forefinger. However, these tips contain a large percentage of needles and, because *needles contain less copper and zinc* than the twigs bearing them, young buds should contain less copper and zinc than the stems which bear them.

Table 2 illustrates the differences which may be found if the copper and zinc content of buds and stems bearing them are investigated.

In Table 2 although all the samples are zinc negative a few are copper positive. The copper positive samples show the same general relationship between bud and stem as do the copper-negative specimens. Furthermore, the copper content of the positive samples does not appear to be related to their zinc content in any way.

In Table 3 several useful points emerge:

(1) The copper and the zinc content of dry needles falls off markedly from year to year. A tendency for the ash content of the needles to decrease with age is not sufficiently great to obscure a falling off in the copper and zinc content of the ash of needles.

TABLE 1.—*PSEUDOTSUGA TAXIFOLIA* (DOUGLAS FIR)
Comparison between Needles and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Needles	Stem	Needles	Stem	Needles	Stem
48.C	3 (100)	7 (250)	18 (1000)	36 (1300)	1.8	2.7
48.H	3 (50)	5 (230)	28 (470)	40 (1700)	6.0	2.3
48. 2	2 (70)	4 (140)	13 (430)	30 (1100)	3.0	2.5
48. 4	2 (60)	3 (120)	15 (460)	37 (1370)	3.2	2.7
48. 5	3 (82)	9 (330)	31 (850)	32 (1300)	3.6	2.8
48. 6	2 (74)	5 (200)	21 (620)	37 (1500)	3.4	2.5
48. 7	3 (110)	3 (150)	16 (490)	50 (2100)	3.2	2.4
48. 8	1 (40)	4 (140)	15 (600)	49 (1700)	2.9	2.5
48. 9	4 (130)	4 (170)	28 (890)	50 (2100)	3.1	2.3
48.10	4 (130)	3 (150)	33 (970)	66 (3000)	3.3	2.2
48.11	4 (120)	5 (160)	37 (970)	68 (2000)	3.8	3.4
48.12	5 (130)	6 (170)	34 (880)	50 (1400)	3.8	3.5
Average...	3 (90)	5 (180)	24 (720)	45 (1700)	3.4	2.7

TABLE 2.—*PSEUDOTSUGA TAXIFOLIA* (DOUGLAS FIR)
Comparison between Tips (Buds) and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Tip	Stem	Tip	Stem	Tip	Stem
48.21	4 (160)	8 (290)	22 (880)	44 (1500)	2.5	3.0
48.22	4 (140)	8 (200)	16 (550)	30 (750)	2.9	4.0
48.23	7 (190)	9 (290)	28 (770)	53 (1600)	3.6	3.2
48.24	3 (70)	8 (250)	20 (440)	39 (1200)	4.5	3.2
48.28	4 (110)	7 (200)	24 (700)	50 (1400)	3.6	3.5
48.29	7 (200)	14 (400)	28 (750)	44 (1300)	3.7	3.5
48.37*	6 (270)	13 (380)	24 (1020)	50 (1400)	2.3	3.5
48.40	7 (250)	7 (280)	23 (750)	42 (1600)	3.0	2.6
48.41	5 (210)	10 (430)	17 (720)	40 (1700)	2.3	2.4
48.42*	12 (460)	14 (420)	27 (1000)	51 (1500)	2.6	3.3
48.45*	5 (180)	10 (380)	24 (890)	49 (1900)	2.7	2.6
48.46*	6 (230)	13 (450)	29 (810)	45 (1600)	2.6	2.9
48.47*	14 (480)	20 (680)	20 (680)	42 (1400)	3.0	2.9
48.48	5 (150)	9 (280)	28 (850)	39 (1200)	3.3	3.3
48.49	8 (250)	9 (260)	30 (950)	44 (1300)	3.1	3.4
48.50	9 (360)	7 (290)	25 (940)	50 (1900)	2.6	2.6
Average....	7 (230)	10 (340)	24 (790)	44 (1400)	3.0	3.1

* Sample now known to be copper positive.

Samples 48.28, 48.29, and 48.40, 48.41 were also originally taken as copper negative but as a result of biogeochemical data they are now believed to be copper positive. Drilling will be necessary if this belief is to be substantiated.

(2) The ash content of stems falls off rapidly as the stems age, and this is sufficient to cause, for at least 1 or 2 years, an appreciable increase in the copper and zinc content of the ashed twigs. The copper in the dry twigs tends to decrease between the first and second year, while the zinc remains more nearly constant.

Although there is probably no such thing as

TABLE 3.—*PSEUDOTSUGA TAXIFOLIA* (DOUGLAS FIR)
Comparison between Tips (Buds) and Older Stems and Needles

TABLE 3.—*PSEUDOTSUGA TAXIFOLIA* (DOUGLAS FIR)
Comparison between Tips (Buds) and Older Stems and Needles

(a) TIPS AND STEMS

Sample No.	Copper			Zinc			Ash Per cent		
	Tips	2nd Yr. Stems	3rd Yr. Stems	Tips	2nd Yr. Stems	3rd Yr. Stems	Tips	2nd Yr.	3rd Yr.
48.15	7 (140)	5 (150)		32 (640)	25 (760)		5.0	3.3	
48.17	4 (120)	4 (130)		32 (1000)	41 (1300)		3.2	3.1	
48.19	9 (240)	7 (320)		25 (670)	38 (1700)		3.7	2.2	
49. 1	10 (230)	8 (310)	4 (170)	42 (1000)	41 (1600)	38 (1600)	4.3	2.6	2.4
49. 2	6 (160)	4 (180)		36 (940)	45 (1800)		3.8	2.5	
49. 3	12 (300)	8 (400)	8 (410)	45 (1100)	45 (2200)	42 (2200)	4.1	2.1	1.9
49. 5		7 (230)	5 (280)		23 (750)	20 (1100)		3.0	1.7
Average.....	8 (200)	6 (250)	6 (290)	35 (890)	37 (1440)	33 (1630)	4.0	2.7	2.0

(b) TIPS AND NEEDLES

Sample No.	Copper			Zinc			Ash Per cent		
	Tips	2nd Yr. Needles	3rd Yr Needles	Tips	2nd Yr Needles	3rd Yr. Needles	Tips	2nd Yr. Needles	3rd Yr. Needles
48.15	7 (140)	1 (29)		32 (640)	18 (510)		5.0	3.5	
48.17	4 (120)	2 (60)		32 (1000)	29 (900)		3.2	3.2	
48.19	9 (240)	2 (60)		25 (670)	18 (600)		3.7	3.1	
49. 1	10 (230)	3 (100)	3 (86)	42 (1000)	17 (550)	17 (480)	4.3	3.1	3.5
49. 2	6 (160)	2 (67)		36 (940)	22 (730)		3.8	3.0	
49. 3	12 (300)	5 (220)	2 (79)	45 (1100)	14 (570)	14 (440)	4.1	2.4	3.1
49. 5		6 (230)	5 (160)		27 (970)	12 (390)		2.8	3.1
Average.....	8 (200)	3 (110)	3 (110)	35 (890)	21 (690)	14 (440)	4.0	3.0	3.2

a normal Douglas Fir with a normal ash and mineral content, it is expedient for illustrative purposes to indicate what may be taken as normal. The following summarizes Tables 1, 2, and 3 and indicates what may be considered normal variations.

	Copper	Zinc	Ash per cent	Cu:Zn
Needles.....	3(90)	24(720)	3.4	.13
	± 50%	± 30%	± 75%	± 50%
Tips or Buds.....	8(250)	25(800)	3.1	.30
	± 50%	± 30%	± 75%	±50%
Stems.....	6(240)	40(1600)	2.7	.15
	± 50%	± 30%	± 75%	± 50%
(1 year's complete growth)				

Specimens from 34 suites which were both copper and zinc negative and which came from widely differing areas, half from near the West Coast and half from the interior of British Columbia (Warren, Delavault, and Irish, 1949), give the following average results:

	Copper	Zinc	Ash per cent	Cu: Zn
Coast (Stems 1 year's growth).....	4.4(195)	38(1620)	2.3	.12
Interior (Stems 1 year's growth)....	5.7(200)	45(1520)	2.8	.13

Variations outside the limits indicated previously we tabulate as anomalous. Using stems as an example we consider as possibly anomalous anything over 9(360) for copper, 60(2400) for zinc, and anything outside the limits .07 to .23 for the Cu:Zn ratio.

Genus *Pinus*

Several species of Pine occur in the Pacific Northwest, but we have found only three species widespread enough to be of value in our preliminary biogeochemical investigations. All the information collected suggests that there are no significant variations in the copper and zinc content of the various species of pine. White (1950) carried out one investigation in which *Pinus ponderosa* and *Pinus albicaulis* were mixed indiscriminately apparently without impairing the results.

In any one area it is usually relatively easy to determine the species of Pine present, and the recognition of the genus presents no difficulty. All pines appear to have two great advantages over other genera: they are exceptionally easy to collect, and variations between needles and stems bearing them is much less than in Douglas Fir and the Spruces.

The Pines as a genus have some drawbacks which occasionally are serious. In many areas they have no low branches. They take longer to dry than do many other genera. At some seasons they are sticky, and this makes salting much more likely. Lastly Pines frequently grow on eskers. These eskers are in some areas more than 100 feet thick; where this is the case the chances of obtaining any indications of economic mineralization are slim.

(a) *Pinus contorta* Douglas var. *latifolia* Engelmann

This species has several local names including lodgepole pine, black pine, jack pine, western jack pine, white pine, and cypress. It is found in a wide range from the southern Yukon to Northern Colorado, Northern Utah, and Northern California. It is locally abundant from the Pacific Coast eastward to Saskatchewan and Eastern Colorado. Botanists disagree as to whether this species and "Shore Pine" represent varieties of the same species or two separate species. We suggest that biogeochemists treat both as one species. The species is most abundant at altitudes from 2000 to 5000 feet. It is adapted to a wide range of sites but makes its best growth on deep, moist, well-drained loam.

Table 4 shows a comparison between needles and stems. As with Douglas Fir, stems tend to carry more copper, both in dry material and in ash, than do the needles they bear. The zinc content of stems and needles is similar and in this respect differs markedly from the distributions noted in Douglas Fir.

The copper content of this species tends, organ for organ, to be a little greater than that in Douglas Fir; however, the zinc content is a little less.

There is little difference in the ash content of needles and stems, and both are lower than their Douglas Fir counterparts.

In Table 5 (a) and (b) the older stems show a lower ash content and a relatively unimpor-

tant decrease of copper and zinc in dry plant material and an increase of these metals in ash.

If only the negative copper and zinc samples be considered we can set up the following normal compositions.

Copper	Zinc	Ash per cent	Cu: Zn
Needles.. 5(220) ± 50%	38(1600) ± 30%	2.3	.13
Tips..... 6(240) ± 50%	42(1700) ± 30%	2.5	.14
Stems.... 6(300) ± 50%	36(1800) ± 30%	2.0	.17
(1 year's complete growth)			

Tables 5 (c), (d), and (e) indicate clearly the type of results to be expected in actual field work. Table 5 (d) represents a reconnaissance suite of samples; mineralization, some of commercial interest, is known in the vicinity of virtually all these positive samples.

Table 5 (e) consists of three groups of samples from the Sullivan Mine area, representative of the groups which we have studied from that vicinity.

(b) *Pinus ponderosa* Lawson (Yellow Pine, *Ponderosa* Pine)

This species has many local names including Western yellow pine, bull pine, yellow pine, British Columbia pine, jack pine, and *Ponderosa* pine. In Canada the tree is confined to the drier portions of the southern interior of British Columbia. It extends south to portions of Montana, Idaho, Oregon, and Washington. It grows on dry well-drained slopes or plateaus, usually between elevations of 1000 and 2500 feet, and appears to demand better-drained soils than the Lodgepole pine.

TABLE 4.—*PINUS CONTORTA* (LODGEPOLE PINE)
Comparison between Needles and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Needles	Stems	Needles	Stems	Needles	Stems
48.14	2 (100)	8 (460)	32 (1700)	27 (1500)	1.9	1.7
48.15	12 (250)	9 (230)	36 (750)	47 (1300)	5.1	3.6
48.16*	13 (450)	12 (400)	39 (1400)	40 (1200)	2.8	3.6
48.17	3 (120)	5 (210)	44 (1800)	40 (1700)	2.4	2.4
48.20*	12 (600)	11 (500)	35 (1700)	29 (1300)	2.1	2.2
49.8	4 (260)	6 (350)	41 (2400)	27 (1600)	1.7	1.7
49.9	5 (290)	7 (410)	28 (1600)	23 (1400)	1.7	1.7
49.10	5 (310)	9 (430)	32 (2100)	32 (1500)	1.5	2.1
49.11	3 (210)	9 (510)	47 (2800)	26 (1500)	1.7	1.7
Average....	6.5 (290)	8.5 (390)	37 (1800)	32 (1400)	2.3	2.3

* Sample now known to be copper positive.

A comparison between needles and stems is shown in Table 6.

The copper and zinc relationships between needles and stems approximate much more closely the relationships noted in Lodgepole pine than those observed in Douglas Fir. The absolute amount of copper in both needles and stems of yellow pine is only about half that in the Lodgepole pine, and the zinc also is somewhat less. We consider this apparent relative deficiency of no particular significance. The trees which are taken as representative were sampled over a wide area under varying conditions, both of climate and of underlying geology. However, agriculturists recognize the area as one in which there are some definitely recognizable mineral deficiencies of which zinc is one. Copper may also be in short supply.

The only justifiable conclusion is that in yellow pine as in Lodgepole pine the needles and stems tend to be much more similar in their copper and zinc content than do the needles and stems of Douglas Fir.

In Table 7 tips and stems are compared, and the results are comparable with those obtained from negative Lodgepole pines.

TABLE 5.—*PINUS CONTORTA* (LODGEPOLE PINE)

(a) COMPARISON BETWEEN TIPS (BUDS) AND STEMS BEARING THEM

Sample No.	Copper		Zinc		Ash	
	Tips	Stems	Tips	Stems	Tips	Stems
48.21	4 (210)	7 (380)	33 (1700)	34 (1800)	1.9	1.8
48.23	9 (300)	7 (280)	97 (3000)	57 (2300)	3.2	2.5
48.28*	7 (290)	15 (650)	46 (1900)	51 (2100)	2.4	2.4
48.29*	7 (300)	12 (400)	41 (1800)	56 (1900)	2.3	3.0
48.30*	8 (270)	12 (470)	27 (900)	23 (900)	3.0	2.6
48.31*	2 (89)	6 (290)	30 (1300)	35 (1700)	2.3	2.1
48.32*	7 (300)	11 (480)	20 (890)	26 (1100)	2.3	2.3
48.33*	7 (340)	15 (840)	43 (2000)	45 (2400)	2.2	1.8
48.34	6 (290)	9 (430)	36 (1700)	33 (1500)	2.1	2.2
48.35	6 (320)	9 (530)	21 (1100)	25 (1400)	1.8	1.8
48.36	3 (140)	7 (330)	34 (1400)	35 (1700)	2.4	2.1
48.37*	7 (310)	11 (560)	39 (1600)	21 (930)	2.4	2.0
48.38*	7 (350)	9 (510)	50 (2300)	38 (2000)	2.1	1.8
48.39*	4 (210)	8 (460)	36 (1700)	23 (1200)	2.1	1.8
48.40*	8 (380)	17 (810)	38 (1800)	31 (1500)	2.1	2.1
48.41	4 (270)	10 (510)	43 (2900)	43 (2200)	1.5	1.9
48.42*	7 (340)	13 (530)	38 (1700)	36 (1500)	2.2	2.4
48.45*	8 (420)	7 (310)	37 (2000)	48 (2000)	1.8	2.4
48.46*	7 (370)	5 (260)	41 (2200)	33 (1700)	1.9	1.9
48.47*	8 (470)	10 (360)	30 (1800)	29 (1100)	1.7	2.5
48.48	7 (390)	7 (250)	55 (3100)	60 (2100)	1.8	2.8
Average.....	6 (300)	10 (460)	40 (1850)	37 (1670)	2.2	2.2

(b) COMPARISON BETWEEN TIPS (BUDS) AND STEMS OF PREVIOUS YEAR'S GROWTH

Sample No.	Copper		Zinc		Ash	
	Tips	Stems	Tips	Stems	Tips	Stems
49.6	9 (320)	10 (540)	35 (1200)	52 (2800)	2.8	1.8
49.7	13 (490)	13 (600)	53 (2000)	42 (1900)	2.6	2.2
49.8	8 (270)	6 (350)	48 (1600)	27 (1600)	3.0	1.7
49.9	7 (200)	7 (410)	43 (1200)	23 (1400)	3.5	1.7
49.10	11 (360)	9 (430)	37 (1200)	32 (1500)	2.6	1.7
49.11	9 (370)	9 (510)	43 (1700)	26 (1500)	2.8	1.8
Average.....	9 (330)	9 (470)	43 (1480)	34 (1780)	2.9	1.8

(c) COPPER AND ZINC CONTENTS OF A NUMBER OF REPRESENTATIVE NEGATIVE SAMPLES OF WELL-DEVELOPED TIPS

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
20.49	7 (300)	44 (1900)	2.3	0.16
24.49	4 (250)	30 (1700)	1.8	0.15
26.49	4 (200)	30 (1400)	2.2	0.15
27.49	5 (260)	37 (1900)	1.9	0.14

* Sample now known to be copper positive

TABLE 5—*Continued*

(c) COPPER AND ZINC CONTENTS OF A NUMBER OF REPRESENTATIVE NEGATIVE SAMPLES OF WELL-DEVELOPED TIPS—*Continued*

Sample No.	Copper	Zinc	Per cent Ash	Cu:Zn
28.49	4 (240)	29 (1500)	1.8	0.16
31.49	5 (240)	38 (1700)	2.3	0.14
32.49	6 (290)	34 (1600)	2.1	0.18
33.49	5 (240)	40 (1900)	2.1	0.12
34.49	4 (270)	33 (2000)	1.6	0.14
35.49	7 (200)	49 (1400)	3.4	0.14
38.49	5 (300)	32 (1700)	1.8	0.17
39.49	4 (200)	32 (1600)	2.0	0.12
41.49	4 (220)	35 (1900)	1.8	0.11
50.49	3 (170)	26 (1500)	1.7	0.12
52.49	6 (330)	35 (1900)	1.8	0.17
60.49	6 (260)	28 (1200)	2.3	0.21
96.49	10 (350)	50 (1800)	2.8	0.20
97.49	9 (370)	52 (2000)	2.5	0.18
114.49	3 (220)	33 (2100)	1.6	0.11
115.49	8 (400)	32 (1500)	2.1	0.27
117.49	5 (250)	37 (1800)	2.0	0.13
Average.....	5.4 (260)	36 (1700)	2.1	0.16

(d) COPPER AND ZINC CONTENTS OF A NUMBER OF REPRESENTATIVE COPPER-POSITIVE AND ZINC-NEGATIVE SAMPLES OF WELL-DEVELOPED TIPS

Sample No.	Copper	Zinc	Ash	Cu:Zn
22.49	9 (490)	31 (1700)	2.2	0.29
23.49	7 (390)	36 (2000)	1.8	0.19
36.49	5 (200)	38 (1600)	2.4	0.13
37.49	10 (380)	37 (1000)	2.6	0.37
40.49	7 (250)	41 (1360)	3.0	0.18
61.49	12 (930)	20 (1500)	1.3	0.61
98.49	8 (460)	33 (1900)	1.7	0.24
Average.....	8 (440)	34 (1600)	2.1	0.29

(e) COPPER AND ZINC CONTENTS OF A NUMBER OF REPRESENTATIVE COPPER-NEGATIVE AND ZINC-POSITIVE SAMPLES OF BOUGHS (TIPS AND SOME SECOND-YEAR GROWTH)

Sample No.	Copper	Zinc	Ash	Cu:Zn
54.46	4 (230)	57 (3000)	1.9	0.077
56.46	3 (170)	60 (3600)	1.7	0.048
57.46	4 (210)	48 (2500)	1.9	0.083
58.46	4 (240)	46 (2500)	1.8	0.096
60.46	5 (260)	86 (4200)	1.1	0.063
Average.....	4 (220)	60 (3200)	1.7	0.07
1.46	5 (250)	360 (16000)	2.2	0.015
6.46	6 (250)	100 (4500)	2.2	0.056

TABLE 5—*Concluded*

(e) COPPER AND ZINC CONTENTS OF A NUMBER OF REPRESENTATIVE COPPER-NEGATIVE AND ZINC-POSITIVE SAMPLES OF BOUGHS (TIPS AND SOME SECOND-YEAR GROWTH)

Sample No.	Copper	Zinc	Ash	Cu:Zn
15.46	4 (200)	90 (4000)	2.2	0.050
18.46	3 (140)	200 (9400)	2.4	0.026
20.46	5 (190)	140 (2700)	2.5	0.032
50.46	4 (170)	220 (8300)	2.6	0.020
52.46	5 (180)	170 (6500)	2.5	0.028
53.46	4 (210)	280 (14000)	2.1	0.016
Average	4 (190)	190 (8200)	2.3	0.03
7.46	5 (110)	160 (4000)	4.0	0.029
8.46	4 (190)	200 (9600)	2.1	0.020
10.46	13 (220)	200 (3500)	5.8	0.060
12.46	6 (340)	86 (5400)	1.6	0.063
16.46	3 (270)	40 (3700)	1.0	0.074
22.46	4 (180)	90 (3700)	2.4	0.049
25.46	5 (220)	160 (7600)	2.1	0.029
26.46	4 (220)	110 (6200)	1.8	0.035
28.46	5 (280)	160 (9200)	1.7	0.030
43.46	4 (250)	54 (3200)	1.7	0.078
Average	5 (230)	130 (5600)	2.4	0.05

TABLE 6.—*PINUS PONDEROSA* (YELLOW PINE PONDEROSA PINE)

Comparison between Needles and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Needles	Stems	Needles	Stems	Needles	Stems
48. 2	4 (140)	3 (150)	28 (1000)	24 (1200)	2.8	2.0
48. 3	4 (120)	3 (190)	25 (780)	18 (940)	3.2	1.6
48. 4	6 (200)	4 (120)	26 (850)	23 (690)	3.0	3.3
48. 5	2 (96)	3 (70)	33 (1300)	35 (1100)	2.6	3.2
48. 7	3 (170)	2 (90)	32 (1500)	26 (1100)	2.0	2.3
48. 8	4 (150)	2 (200)	40 (1500)	32 (1300)	2.6	2.4
48. 9	4 (200)	6 (270)	37 (1800)	30 (1400)	2.0	2.2
48.10	3 (170)	4 (190)	34 (1700)	30 (1300)	2.0	2.3
48.11	5 (230)	4 (150)	60 (2800)	40 (1500)	2.1	2.6
48.12	2 (90)	2 (90)	28 (1000)	33 (1500)	2.7	2.1
Average	4 (160)	3 (150)	34 (1420)	29 (1200)	2.5	2.4

Table 8 lists the copper, zinc, and ash content of a few stems of different ages. A familiar pattern again may be noted. The ash and the copper and zinc content of dry plant material tends to decrease with age. However, the amount of copper and zinc in the ash of second-year stems is usually higher than it is for first-year material. Usually there is a dropping off of the zinc and copper content, even of ash, after the second year, but in some instances this dropping off is not apparent until after the third year.

The reasons for these variations are not of primary interest to the biogeochemist. The important point is that in any investigation a worker must remember the importance of using stems of only one age.

We have no positive samples of yellow pine and consequently we consider it unwise to attempt to suggest normal and anomalous contents for this species.

TABLE 7.—*PINUS PONDEROSA* (YELLOW PINE PONDEROSA PINE)
Comparison between Tips (Buds) and Stems Bearing Them

Sample No.	Copper		Zinc		Ash	
	Tips	Stems	Tips	Stems	Tips	Stems
48.27	6 (280)	8 (380)	25 (1100)	33 (1500)	2.1	2.2
48.48	9 (410)	4 (180)	31 (1300)	25 (1100)	2.3	2.2
48.49	9 (330)	8 (350)	42 (1500)	66 (2700)	2.7	2.4
48.50	10 (330)	12 (430)	28 (910)	30 (1000)	3.0	2.9
Average....	8 (340)	8 (330)	31 (1200)	38 (1600)	2.5	2.4

TABLE 8.—*PINUS PONDEROSA* (YELLOW PINE, PONDEROSA PINE)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.1	7 (230)	5 (230)		53 (1600)	28 (1300)		3.2	2.2	
49.2	5 (170)	4 (220)		37 (1100)	29 (1400)		3.2	2.0	
49.4	5 (120)	5 (170)	3 (160)	19 (460)	29 (910)	30 (1300)	4.1	3.2	2.2
Average...	6 (170)	5 (210)	3 (160)	36 (1100)	29 (1200)	30 (1300)	3.5	2.5	2.2

TABLE 9.—*PINUS ALBICAULIS* (WHITE BARK PINE)
Comparison between Needles and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Needle	Stem	Needle	Stem	Needle	Stem
48.15	6 (220)	7 (180)	32 (1200)	33 (880)	2.7	3.7
48.17	5 (160)	8 (260)	41 (1300)	58 (1900)	3.1	3.0
48.19	6 (190)	5 (170)	26 (800)	26 (900)	3.2	2.9
Average.....	6 (190)	7 (200)	33 (1100)	39 (1230)	3.0	3.2

(c) *Pinus albicaulis* Engelmann (White Bark Pine)

This species is also known as white-stemmed pine and scrub pine. It grows sparingly in British Columbia, usually at altitudes from 3000 to 7000 feet. Its range extends into Washington, Oregon, Idaho, and Montana.

In Table 9 needles and stems are compared. A similarity between the copper, zinc, and ash contents of needles and stems of *Pinus albicaulis* and *Pinus ponderosa* is quite apparent.

In Table 10 tips and stems of the previous year's growth are compared. The ash content of *Pinus albicaulis* appears consistently higher than that of *Pinus ponderosa*. However, considering only the zinc content of the dry plant material, it is reasonable to assume that the zinc content of stems tends to be higher than that of the tips.

TABLE 10.—*PINUS ALBICAULIS* (WHITE BARK PINE)
Comparison between Tips (Buds) and Stems of Previous Year

Sample No.	Copper		Zinc		Ash Per cent	
	Tip	Stem	Tip	Stem	Tip	Stem
49.Y. 10	5 (150)		26 (700)	27 (1600)	3.7	1.8
49.Y. 113	5 (140)		29 (800)	39 (2200)	3.6	1.8
49.Y. 259	9 (280)		47 (1500)	64 (1800)	3.1	3.5
49.Y. 274	4 (150)		26 (830)	44 (1500)	3.0	2.8
49.Y. 279	6 (170)		33 (960)	32 (1300)	3.5	2.4
49.Y. 281	7 (110)		26 (770)	31 (1300)	3.3	2.4
49.Y. 288	5 (130)		30 (810)	37 (1200)	3.7	3.0
49.Y. 290	20 (590)		29 (850)	52 (1900)	1.7	2.8
49.Y. 293	13 (400)		31 (1000)	48 (1500)	2.3	3.1
49.Y. 347	9 (230)		33 (870)	40 (2000)	3.8	2.0
Average.....	8 (230)		31 (910)	41 (1630)	3.2	2.6

TABLE 11.—*PINUS ALBICAULIS* (WHITE BARK PINE)
Comparison between Needles and Stems of Different Ages

Sample No.	Copper		Zinc		Ash Per cent	
	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.
(a) STEMS						
48.15	7 (180)	6 (170)	33 (880)	26 (700)	3.7	3.8
48.17	8 (260)	6 (250)	58 (1900)	54 (2200)	3.0	2.4
48.19	5 (170)	4 (150)	26 (900)	39 (1500)	2.9	2.6
Average...	7 (200)	5 (190)	39 (1230)	40 (1470)	3.2	2.9
(b) NEEDLES						
48.15	6 (220)	3 (180)	32 (1200)	15 (880)	2.7	1.7
48.17	5 (160)	2 (100)	41 (1300)	25 (1700)	3.1	2.0
48.19	6 (190)	2 (150)	26 (800)	22 (1600)	3.2	1.4
Average...	6 (190)	2 (140)	33 (1100)	21 (1390)	3.0	1.7

Table 11, in which needles and stems of different ages are compared, tends to confirm the above observation. The ash content of both stems and needles falls off in the second year, but the falling off is much more conspicuous in needles than in stems.

Genus *Picea*

The spruces are widely distributed throughout the cooler parts of the northern hemisphere. Four species are important in the Pacific Northwest, but we have collected data on only three—*Picea glauca*, *Picea Engelmanni*, and *Picea sitchensis*.

The mineral-bearing habits of all the spruces seem to parallel one another closely.

Even a newcomer can learn to recognize a spruce without difficulty. However the determination of the species may be difficult unless cones can be found. Sometimes it is possible to use geography to determine species, as is the case with *Picea sitchensis* which usually grows at elevations below 1000 feet and in consequence is rarely found far inland.

Usually some low branches are available, but in places their lack may present a problem to the biogeochemist.

The collecting of spruce would be particularly easy if young tips could be used with confidence.

Unfortunately the work we have done suggests that such is not the case, and indeed our limited data hint that, especially for copper, spruce tips, particularly very young ones, are quite unreliable.

Engelmanni consistently runs a little higher than that of Douglas fir or the pines.

Table 13 (a) compares tips and stems bearing them, and Table 13 (b) contrasts tips and stems of previous year's growth. The tips of

TABLE 12.—*PICEA ENGELMANNI* (ENGELMANN SPRUCE)
Comparison between Needles and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Needle	Stem	Needle	Stem	Needle	Stem
48.C.	2 (50)	10 (320)	34 (870)	57 (1800)	3.9	3.1
48.14	5 (130)	6 (150)	69 (1800)	77 (1900)	3.8	4.1
48.16	6 (150)	13 (260)	40 (1000)	79 (1500)	4.0	5.1
48.17	6 (160)	9 (170)	40 (1100)	70 (1200)	3.5	5.7
48.19	5 (150)	12 (300)	36 (1300)	65 (1600)	3.3	4.0
49. 3	4 (120)	4 (110)	43 (1300)	60 (1700)	3.2	3.6
49. 5	6 (160)	17 (370)	57 (1500)	62 (1400)	3.7	4.7
49.10	4 (200)	11 (480)	23 (1000)	64 (2700)	2.2	2.4
49.11	2 (86)	10 (430)	28 (1000)	38 (1600)	2.9	2.3
Average...	4 (130)	10 (290)	41 (1200)	64 (1700)	3.4	3.9

Most of our work has been with *Picea Engelmanni*, and all our results must be built on and around this species.

(a) *Picea Engelmanni* Parry

Although generally called Engelmann spruce it is also known as Mountain spruce, Rocky Mountain spruce, and western white spruce.

Insofar as biogeochemistry in the Pacific Northwest is concerned, *Picea Engelmanni* is by far the most important of the spruces. It does not occur west of the coast mountains nor north of the Nechako River and the Big Bend of the Fraser River. However, it is found from the Nechako to Colorado and Utah in the mountains. It favors elevations from 3000 to 5000 feet in the central part of its range but descends to 1000 in the north and ascends to 8000 in Colorado. Its best growth is reported from deep rich loamy soils with a high moisture content. Occasionally its shares new burns with lodgepole pine.

In Table 12 the ash and mineral content of needles and stems may be compared. The relationship between needles and stems is similar to that in Douglas fir, not to that in the pines; the stems are richer in both copper and zinc than are the needles. The ash content of *Picea*

Table 13 (b) are very young tips, barely having enough growth to enable effective collecting, whereas the tips of Table 13 (a) are 2 to 3 months old. Eliminating the samples known to be positive we may tentatively conclude that:

(1) Very young tips have the greatest ash content.

(2) Developed and older needles have a lower ash content than the stems bearing them.

(3) Older stems are considerably lower in ash than are stems 1 year old.

(4) Stems which contain 1 year's growth appear to be the most reliable for biogeochemistry. We have no explanations for some of the obvious exceptions to the above generalization.

If we eliminate all the known positives it is possible tentatively to propose some normal contents:

	Copper	Zinc	Ash per cent	Cu:Zn
Needles..	4(120) ± 50%	40(1200) ± 30%	3.4	.10
Tips.....	10(260) ± 50%	45(1300) ± 30%	3.6	.22
Stems....	9(320) ± 50%	60(1800) ± 30%	3.2	.15
(1 year's complete growth)				

On the basis of Tables 12 and 13 (a) and (b) tips are most unreliable, especially with respect to copper. Indeed in Table 12 samples Nos. 16 and 19 appear perfectly normal, and one or

TABLE 13.—*PICEA*

Spec. No.	Copper		Zinc		Ash Per cent	
	Tips	Stems	Tips	Stems	Tips	Stems
(a). PICEA ENGELMANNI (Engelmann Spruce) Comparison between Tips (Buds) and Stems Bearing Them						
48.21	2 (100)	6 (230)	27 (1400)	47 (1800)	1.9	2.6
48.22	5 (170)	7 (270)	42 (1400)	33 (1300)	2.9	2.5
48.23	11 (410)	7 (240)	53 (2000)	62 (2000)	3.7	3.1
48.24	7 (190)	11 (250)	51 (1400)	52 (1200)	3.6	4.7
48.25	5 (180)	8 (250)	29 (1000)	42 (1200)	2.8	3.4
48.28	9 (300)	21 (570)	26 (800)	32 (870)	3.2	3.7
48.29	7 (220)	16 (460)	36 (1100)	42 (1200)	3.1	3.4
48.31*	7 (220)	16 (520)	31 (970)	35 (1100)	3.2	3.1
48.33*	6 (190)	13 (380)	38 (1200)	68 (2000)	3.1	3.4
48.35	4 (120)	6 (200)	38 (1050)	39 (1200)	3.6	3.2
48.36	6 (190)	7 (160)	39 (1200)	50 (1200)	3.1	4.2
48.39	6 (170)	10 (260)	49 (1400)	77 (1900)	3.7	4.0
48.40	4 (150)	9 (260)	28 (1000)	50 (1400)	3.7	3.6
48.41	6 (210)	16 (640)	40 (1400)	48 (1600)	2.8	2.9
48.47*	11 (340)	18 (590)	34 (1000)	36 (1200)	3.4	3.0
Average.....	6 (210)	11 (350)	37 (1220)	48 (1410)	3.2	3.4
(b). PICEA ENGELMANNI (Engelmann Spruce) Comparison between Tips (Buds) and Stems of Previous Year's Growth						
49. 3	7 (160)	4 (110)	49 (1100)	60 (1700)	4.4	3.6
49. 7	25 (570)	12 (560)	72 (1700)	100 (4400)	4.3	2.2
49. 8	8 (170)	9 (330)	65 (1400)	72 (2700)	4.6	2.7
49.10	29 (670)	11 (480)	62 (1400)	64 (2700)	4.3	2.4
49.11	10 (300)	10 (430)	50 (1500)	38 (1600)	3.3	2.3
49.Y.33†	16 (230)	5 (210)	95 (1300)	115 (4800)	7.0	2.4
49.Y.43†	25 (540)	5 (190)	90 (2000)	102 (3900)	4.6	2.6
49.Y.101	3 (70)	5 (250)	49 (1200)	52 (2600)	4.2	2.0
49.Y.147	13 (270)	13 (520)	94 (2000)	112 (4500)	4.8	2.5
49.Y.210	12 (240)	8 (250)	76 (1500)	86 (2700)	5.0	3.2
49.Y.424†	6 (200)	6 (200)	56 (1900)	64 (2200)	3.0	2.9
Average....	14 (310)	8 (320)	69 (1550)	79 (3070)	4.5	2.6

(c). PICEA SITCHENSIS (Sitka Spruce)
Suite of Samples from Vicinity of Buried Copper Mineralization, Fairview Mine (Britannia), B.C. (Boughs)

Suite 46B Sample No.	Copper	Zinc	Ash	Cu:Zn
1	15 (580)	28 (1100)	2.6	0.5
2	14 (500)	31 (1100)	2.8	0.5
3	6 (190)	32 (1000)	3.1	0.2
7	16 (640)	32 (1300)	2.5	0.5
8	10 (450)	24 (1100)	2.2	0.4
9	4 (150)	10 (380)	2.6	0.4

* These samples are now known to come from copper-positive areas. Samples 48.28, 48.29, 48.40, and 48.41 were all taken as copper negative but may now be considered as probably copper positive.

† These samples are now definitely known to come from zinc positive areas. It is possible that some of the other high zincs should be considered zinc positive.

(c). PICEA SITCHENSIS (Sitka Spruce)—*Continued*

Suite 46B Sample No.	Copper	Zinc	Ash	Cu:m
10	21 (650)	49 (1500)	3.2	0.4
12	7 (330)	26 (1200)	2.1	0.3
14	9 (390)	31 (1300)	2.3	0.3
16	7 (370)	35 (1800)	1.9	0.2
17	20 (740)	26 (960)	2.7	0.8
18	20 (770)	23 (880)	2.6	0.9
19	10 (370)	28 (1040)	2.7	0.4
21	5 (210)	30 (1200)	2.4	0.16
22	25 (800)	27 (870)	3.1	0.9
24	5 (160)	35 (1100)	3.2	0.14
25	5 (170)	34 (1100)	3.0	0.15
26	3 (100)	28 (930)	3.0	0.11
Average.....	11 (420)	29 (1100)	2.7	0.40

(d). PICEA GLAUCA (White Spruce)

Copper, Zinc, and Ash Content of Normal Tips

Sample No.	Copper	Zinc	Ash	Cu:Zn
49. 20	6 (230)	48 (1800)	2.6	0.12
49. 24	5 (190)	38 (1400)	2.6	0.19
49. 25	4 (120)	43 (1300)	3.3	0.09
49. 26	5 (170)	48 (1500)	3.1	0.12
49. 27	4 (160)	32 (1100)	2.8	0.14
49. 28	5 (180)	33 (1200)	2.7	0.15
49. 31	6 (190)	49 (1600)	3.1	0.12
49. 32	8 (210)	51 (1300)	3.8	0.16
49. 34	3 (160)	35 (1600)	2.2	0.10
49. 35	4 (130)	50 (1500)	3.3	0.09
49. 38	4 (170)	38 (1600)	2.4	0.11
49. 39	4 (190)	34 (1400)	2.4	0.13
49. 40	7 (230)	45 (1400)	3.2	0.17
49. 41	5 (200)	29 (1000)	2.8	0.19
49. 60	5 (200)	30 (1100)	2.7	0.18
49.114	3 (160)	28 (1300)	2.2	0.12
Average.....	5 (180)	39 (1400)	2.8	0.14

(e). PICEA GLAUCA (White Spruce)

Copper, Zinc, and Ash Content of Some Copper-Positive Tips

Sample No.	Copper	Zinc	Ash	Cu:Zn
49.21	8 (270)	43 (1500)	2.9	0.19
49.22	10 (430)	40 (1700)	2.3	0.25
49.23	8 (330)	31 (1300)	2.4	0.26
49.29	6 (210)	48 (1600)	3.0	0.14
49.30	13 (430)	48 (1600)	3.0	0.27
49.36	12 (370)	38 (1200)	3.2	0.32
49.37	10 (380)	44 (1700)	2.6	0.23
49.46	4 (130)	40 (1100)	3.5	0.11
49.98	11 (410)	43 (1600)	2.7	0.26
Average.....	9 (330)	42 (1500)	2.8	0.23

two samples, which to the best of our knowledge are both copper and zinc negative, give positive results.

In Tables 13 (a) and (b) the results are more obvious and, on the whole, are satisfactory. Recent development work in the vicinity of some of the "negative" samples suggests they may better be considered as positive, a conclusion obviously indicated when the collection was analyzed.

(b) *Picea sitchensis* (Bong.) Carrière
Sitka spruce

This species is also known as Menzies spruce, tideland spruce, and coast spruce. It extends along the coast from Alaska to Oregon and is the largest and most imposing of the spruces and is particularly important in the Queen Charlotte Islands.

Unfortunately we have as yet been unable to make any detailed investigations of normal members of this species.

However, we have one excellent suite from a copper-positive area; this is given in Table 13 (c). Although many individual samples are low the suite as a whole is relatively high. Furthermore this is a suite of "boughs" which includes many older needles and therefore may safely be assumed to be relatively low in copper. These samples all came from an area of heavy rainfall, possibly as much as 80 inches annually, and thus the area is apt to be relatively highly leached.

(c) *Picea glauca* (Moench) Voss
White spruce

This spruce is also known as single spruce, skunk spruce, northern spruce, pine, cat spruce, yellow spruce, and others.

The white spruce is the most important of the Canadian spruces. In the Pacific Northwest it is abundant in Alaska, the Yukon, and British Columbia but does not extend into Washington and Oregon. With black spruce and tamarack it forms the northern limit of tree growth. It grows best on well-drained, moist, gravelly soil along streams and around the borders of swamps and lakes.

We have had no opportunity to collect systematically from known areas. Fortunately a large collection of buds taken during exploration work is available, and from our present knowledge the samples in Table 13 (d) may, with reasonable assurance, be assumed to be normal.

The specimens whose analyses are given in Table 13 (e) are all from suites now considered copper positive. The differences in the copper content of the two sets of specimens are marked although the copper content of some of the specimens in Table 13 (e) is normal.

None of the samples taken for Table 13 (e) was considered zinc positive, but some of the suites of which they were a part were determined to be zinc positive. The failure of these spruce trees to respond to zinc in the same manner as their associates is not explained. We think the explanation will have something to do with the fact that many of these spruces were growing near the main water table of the lakes near where the samples were taken. Zinc is both more abundant and more soluble than copper, and smaller percentage variations are significant for zinc than for copper. By inference, copper anomalies might in some conditions be easier to spot than zinc abnormalities.

A discerning reader may now be asking why Table 13 (b) which contains tips of normal *Picea Engelmanni* specimens should run so high in copper in comparison with the normal samples in Tables 13 (a) and (d).

Further work must be done before this problem can be answered. Three possibilities have been considered: (1) Marine sediments are reported to contain abnormally large amounts of copper, and marine sediments occur near where some of the high-copper-bearing tips were collected. (2) Many samples dealt with in Table 13 (b) come from well-mineralized areas. Commercially the mineralization is zinc, and the copper content is insignificant. However, the sphalerite in the area contains copper, and this copper content may be sufficient to cause some of the anomalies. (3) Many of the samples reported in Table 13 (b) were very young, with extremely small tips. Fortunately the size of many of the tips was noted during collection. Thus we know that many of the high-copper tips did correspond with the earliest growth which could be collected. This possible relationship between high copper and early growth might be investigated further.

Once again all these unanswered problems serve to show how careful a biogeochemist must be when he starts work in a new area. Constants and normals must be established, if possible on a statistical basis, before any results can be interpreted intelligently.

Genus *Thuja*

(a) *Thuja plicata* (Donn)
Western Red Cedar

The arbor-vitae are usually referred to as cedars in North America. Actually the true cedars belong to the genus *Cedrus*, and none are native to North America.

The western red cedar is the member of the genus native to the Pacific Northwest. The species is found on the Alaska panhandle, along the coast of British Columbia, Washington, and Oregon, and in the valleys of the interior wet belts of British Columbia, Washington, Idaho, and western Montana. It prefers a deep moist porous soil on cool slopes and in gulches.

Thuja plicata is known locally by many other names including giant arbor-vitae, red cedar, British Columbia cedar, British Columbia red cedar, giant cedar, and western cedar.

Unfortunately the results given in Tables 14, 15, and 16 represent our only data on this species, and as may be noted we have no copper-positive suites at all.

Cedar does not tolerate too dry conditions, and it therefore is frequently missing from many areas where mineralization is being investigated.

About the only justifiable conclusions at this time are:

(1) The zinc content of the stems even with some scales still adhering is normally much lower than that of any of the other evergreens yet reported.

(2) The tips seem useless as a guide to zinc concentrations, but the stems appear to be satisfactory.

As a foundation for further studies we suggest that the following may be considered normal:

	Copper	Zinc	Ash per cent	Cu:Zn
Needles..	4(110) ± 50%	12(340) ± 30%	3.5	.33
Tips.....	4(110) ± 50%	14(390) ± 30%	3.6	.29
Stems....	4(100) ± 50%	26(700) ± 30%	3.7	.15
(1 year's complete growth)				

TABLE 14.—*THUJA PLICATA* (WESTERN RED CEDAR)
Comparison between Needles and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Needles	Stems	Needles	Stems	Needles	Stems
48 H.	3 (100)	2 (80)	12 (400)	15 (600)	3.0	2.5
48 I.	3 (90)	2 (90)	8 (200)	14 (550)	4.0	2.6
Average.....	3 (95)	2 (85)	10 (300)	14 (575)	3.5	2.5

Genus *Juniperus*

(a) *Juniperus scopulorum* Sargent
Rocky Mountain Juniper

This variety is also known as the Rocky Mountain red cedar, red cedar, and western juniper.

It is found in the foothills of Montana and western Alberta and westward in Idaho, Washington, Oregon, and southern British Columbia. It is usually found at higher altitudes on dry rocky or sandy soils but grows best in moist canyon bottoms.

(b) *Juniperus communis* L. var. *depressa* Pursh
Dwarf Juniper

The authors have found it impractical to separate this species from a closely related variety *Juniperus horizontalis* Moench. Both are widely distributed in western Canada in relatively dry areas, and in Washington and Idaho. Table 18 may contain both varieties.

Tables 17 and 18 present the limited data we have on these species. No zinc-positive samples are available.

TABLE 15.—*THUJA PLICATA* (WESTERN RED CEDAR)
Comparison between Tips and Stems of Previous Year

Sample No.	Copper		Zinc		Ash Per cent	
	Tips	Stems†	Tips	Stems†	Tips	Stems†
49.Y. 13	5 (120)	4 (100)	17 (380)	38 (950)	4.4	4.0
49.Y. 42*	6 (180)	4 (100)	20 (590)	79 (2200)	3.4	3.6
49.Y. 46*	2 (70)	4 (100)	15 (500)	37 (1000)	3.4	3.7
49.Y. 49	7 (200)	4 (100)	15 (400)	27 (800)	3.7	3.5
49.Y. 52	6 (220)	3 (90)	14 (480)	13 (400)	2.4	3.3
49.Y.179	6 (160)	3 (80)	18 (440)	32 (840)	4.0	3.7
49.Y.182	4 (110)	4 (100)	13 (350)	27 (650)	3.7	4.0
49.Y.200*	3 (70)	3 (70)	14 (340)	77 (1700)	4.1	4.4
49.Y.237*	3 (90)	3 (90)	12 (350)	43 (1300)	3.4	3.4
49.Y.406*	3 (110)	4 (100)	13 (410)	72 (1800)	3.3	3.9
Average.....	4 (130)	4 (90)	15 (420)	44 (1160)	3.6	3.7

* Samples known to be zinc positive.
† With base of green scales adhering.

TABLE 16.—*THUJA PLICATA* (WESTERN RED CEDAR)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash, Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.2	1 (50)	2 (85)	3 (100)	9 (310)	11 (400)	12 (330)	2.9	2.9	3.6

TABLE 17.—*JUNIPERUS SCOPULORUM* (ROCKY MOUNTAIN JUNIPER)
Comparison between Tips and Stems Bearing Them
(Some 2nd year material included)

Sample No.	Copper		Zinc		Ash Per cent	
	Tips	Stems	Tips	Stems	Tips	Stems
48. 9	4 (70)	2 (40)	13 (230)	12 (250)	5.7	4.8
48.12	5 (110)	4 (90)	17 (360)	14 (310)	4.6	4.6
48.27	9 (220)	6 (170)	15 (370)	13 (360)	4.0	3.6
48.40*	5 (150)	5 (130)	18 (490)	8 (190)	3.7	4.2
48.41*	21 (520)	5 (110)	17 (420)	9 (200)	4.0	4.6
48.47*	8 (130)	13 (180)	9 (130)	7 (95)	6.7	7.2
48.50†	18 (380)	8 (170)	16 (360)	10 (220)	4.7	4.6
49.50"A".	7 (160)	6 (200)	18 (420)	9 (300)	4.3	3.0
Average.....	10 (220)	6 (140)	15 (350)	10 (240)	4.7	4.6

* These samples are now thought to be copper positive.
† The unusually high copper content of this tip caused a check sample to be taken. This check sample gave the results reported for sample 49.50"A". Salting may be responsible for the high copper in 48.50.

In spite of this limited data the following conclusions seem valid:

(1) Both junipers have a relatively high ash content.

(2) Both junipers in terms of ash have a markedly higher copper and zinc content in their tips than in the stems bearing them.

(3) Both junipers contain copper in amounts

TABLE 18.—*JUNIPERUS COMMUNIS* (DWARF OR COMMON JUNIPER)
Comparison between Tips and Stems Bearing Them
(Some 2nd year material included)

Sample No.	Copper		Zinc		Ash Per cent	
	Tips	Stems	Tips	Stems	Tips	Stems
48. 8	6 (140)	3 (60)	15 (310)	23 (450)	4.8	5.1
48.10	5 (140)	2 (60)	14 (390)	27 (860)	3.5	3.1
48.16	8 (120)	6 (120)	15 (330)	14 (270)	4.2	5.2
48.17	3 (60)	5 (85)	18 (380)	16 (280)	4.7	5.8
48.19	5 (140)	5 (95)	21 (600)	12 (230)	3.5	5.2
48.21	4 (90)	3 (55)	19 (460)	12 (220)	4.1	5.3
48.22	6 (150)	13 (230)	11 (290)	13 (230)	3.8	5.6
48.23	7 (200)	10 (110)	24 (690)	18 (210)	2.9	9.0
48.31	13 (390)	8 (200)	19 (570)	23 (590)	3.3	3.9
48.34	3 (80)	5 (120)	18 (470)	20 (410)	3.8	4.7
48.35	4 (120)	5 (130)	18 (550)	17 (380)	3.3	4.3
48.38	3 (100)	4 (75)	20 (670)	19 (350)	3.0	5.4
48.40	7 (220)	5 (130)	19 (600)	17 (440)	3.2	3.9
48.42	16 (430)	6 (120)	27 (710)	28 (580)	3.8	4.8
Average.....	6 (170)	6 (110)	18 (500)	18 (390)	3.7	5.1

TABLE 19.—*TSUGA HETEROPHYLLA* (HEMLOCK, "ALASKA PINE")
Comparison between 1st year Stems and 1st and 2nd year Needles

Sample No.	Copper		Zinc		Ash Per cent	
	Needles	Stems	Needles	Stems	Needles	Stems
49.Y. 17	2 (70)	7 (300)	19 (520)	38 (1700)	3.6	2.2
49.Y. 37*	2 (100)	3 (120)	10 (400)	61 (2400)	2.6	2.5
49.Y. 47*	3 (80)	5 (170)	20 (510)	83 (2800)	3.5	2.9
49.Y. 48*	3 (110)	6 (250)	12 (440)	53 (2300)	2.7	2.3
49.Y. 50*	3 (140)	8 (330)	11 (450)	63 (2600)	2.5	2.4
49.Y. 146	3 (120)	7 (330)	9 (390)	42 (1900)	2.4	2.2
49.Y. 149	3 (110)	7 (250)	12 (450)	46 (1600)	2.7	2.8
49.Y. 299	2 (90)	6 (210)	9 (420)	61 (2300)	2.2	2.7
49.Y. 323	2 (65)	9 (350)	9 (310)	53 (2200)	3.0	2.4
49.Y. 402*	2 (90)	5 (280)	15 (670)	48 (2700)	2.2	1.8
Average.....	2.5 (100)	6 (260)	13 (460)	55 (2250)	2.7	2.4

* Samples from areas now considered to be possibly zinc positive.

comparable with other genera of the Gymnospermae.

(4) The zinc content of both tips and stems is the lowest of any of the Gymnospermae we investigated.

(5) The response in both species of juniper to known copper mineralization is erratic; in a few samples it is marked but in other cases is not noticeable.

The junipers are not a genus particularly well suited for biogeochemical prospecting. It is difficult to select growth of a particular organ of a precise age from a juniper, and because of the very nature of its occurrence one would expect to have to be close to mineralization before excess metal would become available to a tree.

Bearing in mind the above we suggest that for tips and stems the following be considered normal:

	Copper	Zinc	Ash per cent	Cu:Zn
Tips.....	5(120) ± 50%	17(400) ± 30%	4.2	.30
Stems.... (Young)	5(100) ± 50%	15(300) ± 30%	4.8	.33

TABLE 20.—*TSUGA*

TSUGA HETEROPHYLLA (Hemlock, "Alaska Pine")

Comparison between Stems of Different Ages

Sample No.	Copper		Zinc		Ash Per cent	
	1st Year	2nd Year	1st Year	2nd Year	1st Yr.	2nd Yr.
49.Y. 17	7 (300)	6 (300)	38 (1700)	32 (1500)	2.2	2.0
49.Y. 37*	3 (120)	3 (130)	61 (2400)	51 (2100)	2.5	2.5
49.Y. 47*	5 (170)	6 (210)	83 (2800)	74 (2800)	2.9	2.7
49.Y. 48*	6 (250)	6 (190)	53 (2300)	68 (2300)	2.3	3.0
49.Y. 50*	8 (330)	9 (430)	63 (2600)	62 (3000)	2.4	2.1
49.Y. 146	7 (330)	7 (300)	42 (1900)	67 (2700)	2.2	2.5
49.Y. 149	7 (250)	4 (180)	46 (1600)	54 (2200)	2.8	2.4
49.Y. 299	6 (210)	4 (170)	61 (2300)	72 (2700)	2.7	2.4
49.Y. 323	9 (350)	7 (330)	53 (2200)	44 (2100)	2.4	2.1
49.Y. 402*	5 (280)	6 (330)	48 (2700)	56 (3200)	1.8	1.7
Average.....	6 (260)	6 (260)	55 (2250)	48 (2460)	2.4	2.3

(a). TSUGA HETEROPHYLLA (Hemlock)

Copper, Zinc, and Ash Content of Boughs, Britannia

(Less than 150 feet below copper plant)

Suite 46B Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
27	90 (2400)	200 (5300)	3.8	0.4
28	96 (3100)	198 (6400)	3.1	0.4
29	54 (1700)	37 (1200)	3.2	1.5
30	23 (880)	23 (880)	2.6	1.0
38	690 (19700)	1300 (37000)	3.5	0.5
39	150 (5600)	93 (3400)	2.7	1.5
40	190 (6100)	120 (3900)	3.1	1.6
41	295 (8400)	180 (5100)	3.5	1.6
44	190 (4600)	110 (2700)	4.1	1.8
45	80 (2600)	74 (2400)	3.1	1.1
Average.....	190 (5500)	230 (6800)	3.3	1.1†

(b). TSUGA HETEROPHYLLA (Hemlock)

Copper, Zinc, and Ash Content of Boughs, Britannia

(More than 150 feet below copper plant)

Suite 46B Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
31	31 (800)	32 (800)	3.9	1.0
32	54 (1500)	33 (890)	3.7	1.6
33	42 (970)	51 (1200)	4.3	0.7
34	36 (820)	49 (1100)	4.4	0.7
35	60 (1700)	58 (1700)	3.5	1.0
36	22 (840)	23 (880)	2.6	1.0
37	22 (650)	52 (1500)	3.4	0.4
46	110 (3200)	110 (3200)	3.4	1.0
47	78 (2700)	45 (1600)	2.9	1.7
48	23 (680)	53 (1600)	3.4	0.4
49	41 (1200)	32 (970)	3.3	1.3
50	9 (300)	32 (1100)	3.0	0.3
51	9 (400)	20 (900)	2.2	0.4
Average.....	41 (1200)	45 (1300)	3.4	0.9

* Samples from areas now considered to be possibly zinc positive.

† Cu:Zn ratio from averaged totals = 190/230 = 0.8

(c). TSUGA HETEROPHYLLA (Hemlock)

Copper, Zinc, and Ash Content of Boughs, Britannia
(Different drainage from that below copper plant)

Suite 46B Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
54	4 (170)	59 (2500)	2.4	0.07
55	5 (180)	64 (2400)	2.7	0.08
56	11 (340)	35 (1100)	3.2	0.30
57	13 (430)	34 (1100)	3.0	0.40
Average	8 (280)	48 (1800)	2.8	0.2

(d). TSUGA HETEROPHYLLA (Hemlock)

(Tips)

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49. 35	5 (190)	12 (430)	2.9	0.44
49. 48	8 (250)	20 (620)	3.1	0.41
49. 49	4 (180)	13 (620)	2.2	0.30
49. 52	6 (260)	21 (840)	2.5	0.31
49. 76	4 (160)	13 (530)	2.4	0.31
49. 78	5 (200)	19 (760)	2.4	0.27
49.108	5 (180)	17 (560)	3.0	0.32
49.112	6 (230)	14 (540)	2.6	0.43
49.113	5 (190)	12 (460)	2.6	0.42
Average	5 (200)	16 (600)	2.6	0.36

(e). TSUGA MERTENSIANA (Mountain Hemlock)

(Tips)

Sampl No.	Copper	Zinc	Ash Per cent	Cu:Zn
49.63	3 (120)	12 (450)	2.8	0.28
49.66	4 (190)	19 (880)	2.1	0.22
49.67	4 (170)	14 (560)	2.4	0.30
49.76	4 (160)	15 (520)	2.9	0.30
49.79	4 (190)	11 (550)	2.1	0.35
Average	4 (170)	14 (590)	2.5	0.29

Genus *Tsuga*

Two species of hemlock occur in the Pacific Northwest. They may be classed as tolerant trees because they can grow in the shade of, and in competition with, other trees. Both trees demand much moisture.

(a) *Tsuga heterophylla* (Rafinesque-Schmaltz) Sargent Hemlock

This species also is known as British Columbia hemlock and as Alaska pine. It is a large and relatively slow-growing tree and hence has never been a popular tree for biogeochemical investigations; the time consumed in collecting a satisfactory sample usually is longer than for other species or genera growing in the same area.

Hemlock occurs throughout the coastal and wet belts of southern Alaska, British Columbia, Washington, Idaho, and Oregon. All the samples in Tables 19 and 20 come from a wet belt in the southern interior of British Columbia, and possibly the results are not typical of this species elsewhere.

Tables 19 and 20 show that in many respects

it resembles Douglas fir. Hemlock needles are much lower in both copper and zinc than the stems which bear them, regardless of whether they are compared on the basis of ashed or dry-plant material. Similarly both hemlock and Douglas fir appear to have a higher ash content in their needles than in the stems bearing them.

Fortunately there seems to be no marked difference in the copper and zinc content of the first- and second-year stems. This may be important because it may simplify the problem of getting satisfactory samples where the growth is small.

Tentatively we suggest as normal for hemlock

	Copper	Zinc	Ash per cent	Cu: Zn
Needles..	3(100) ± 50%	13 (460) ± 30%	2.7	.23
Stems....	6(260) ± 50%	50(2100) ± 30%	2.4	.12
(One full year's growth)				

A slight change between the above figures and those in Tables 19 and 20 has been made because after the preliminary results were prepared drilling and development work showed, as one might have hoped, that some of the supposedly negative samples were positive.

We have already described three suites of specimens taken under abnormal conditions but under conditions which enable us to show the amounts of copper and zinc this species of tree can absorb without exhibiting any ill, or indeed any visible, effects (Warren and Delavault, 1949). Table 20 (a) shows samples taken from within 150 feet of the copper recovery plant (by precipitation on scrap iron). Table 20 (b) shows samples taken beyond 150 feet of the plant. Table 20 (c) shows samples taken near by but belonging to a different drainage area. The zinc anomalies decreased within short distances; the copper anomalies extend well beyond the 150-foot suite.

Again we must point out that all the specimens in Tables 20 (a), (b), and (c) are of boughs and that these boughs are normally much lower in metal content than are the twigs.

In the light of our present knowledge, the samples in Table 20 (c) suggest that there might be zinc and/or copper in the vicinity, but not in the quantities found near the copper plant.

During 1949 a number of samples of *Tsuga heterophylla* were collected in Tweedsmuir Park. Table 20 (d) represents a typical collection of normal tips.

(b) *Tsuga Mertensiana* (Bong) Carrière Mountain Hemlock

This species is also called black hemlock. It is found throughout much the same range as *Tsuga heterophylla* but at higher altitudes, usually near timber line at altitudes of 2500 to 6000 feet, but it descends nearly to sea level in the more exposed and wetter situations in the north.

No satisfactory positive and negative collections are available for comparison, but Table 20 (e) of normal tips taken from the same general area as the samples in Table 20 (d) suggests that the two members of the genus *Tsuga* behave similarly.

Genus *Abies*

The *Abies* or true firs are widely distributed in the Pacific Northwest where three species—*Abies lasiocarpa*, *Abies amabilis*, and *Abies grandis*—are known.

By far the most important of the true firs is *Abies lasiocarpa*, and fortunately we have some data about this species. Critical data about the other two species are sadly lacking.

(a) *Abies lasiocarpa* (Hooker) Nuttall Alpine Fir

This species has many local names; it is variously known as mountain fir, white balsam, white fir, Western balsam fir, caribou fir, and Rocky Mountain fir. Except for a few areas in the vicinity of the southern coastal region this species is widespread throughout the whole of the Pacific Northwest especially at altitudes between 2000 and 7000 feet. Like many other species it thrives best on moist well-drained loam soils, but it can tolerate quite dry sites.

Tables 21 and 21 (a) illustrate some of the information we have collected dealing with this species. We have no comparable results for needles, but available data suggest that needles probably are a little lower in copper and in zinc than are the stems which bear them.

Possibly the following represents normal contents for this species:

	Copper	Zinc	Ash per cent	Cu: Zn
Needles..	5(180) ± 50%	30(1080) ± 30%	3.6	.17
Tips..... (Buds)	6(220) ± 50%	32(1200) ± 30%	3.6	.19
Stems.... (1 year's growth)	6(200) ± 50%	45(1500) ± 30%	3.3	.13

The discrepancy between the ash content of the above and that given in Tables 21 and 21 (a) results from our attempting to reconcile two sets of samples taken over 300 miles apart with widely differing climates. The trees have widely different ash contents. We have chosen the more southerly collection as more likely to represent the ash content of the area as a whole.

One feature which might prove useful is that the tips tend to show less variations from the normal than the tips of some other species, notably *Picea Engelmanni*. If this feature be substantiated by other workers it would be a most useful fact. Collecting tips of this species is a delightfully simple job compared with collecting stems of one year's growth!

We have no suites strongly positive of either zinc or copper mineralization. We do have a number of specimens from weakly mineralized copper areas shown in Table 21 (b).

Suites of tips from areas comparatively as well mineralized with zinc as those in Table 21 (b) were in copper gave no significant results. This may indicate that zinc is less easy to detect by means of this species. It may indicate, and this appears more probable, that we took our samples too close to the main water table of the

TABLE 21.—*ABIES*

ABIES LASIOCARPA (Rocky Mountain Fir, Western Balsam Fir)

Comparison between Stems of Different Ages

Sample No.	Copper		Zinc		Ash Per cent	
	1st Year	2nd Year	1st Yr.	2nd Yr.	1st Year	2nd Year
49.Y. 53	7 (170)	7 (200)	69 (1700)	76 (2300)	3.9	3.3
49.Y. 56	5 (150)	4 (130)	52 (1400)	58 (1800)	3.6	3.3
49.Y. 58	4 (120)	8 (190)	67 (2000)	77 (1900)	3.3	4.1
49.Y. 78	5 (140)	5 (130)	30 (830)	31 (820)	3.6	3.7
49.Y. 95	6 (150)	5 (140)	43 (1100)	45 (1300)	3.9	3.5
49.Y. 117	8 (240)	8 (260)	55 (1600)	49 (1600)	3.4	3.1
49.Y. 120	6 (140)	7 (180)	32 (830)	51 (1400)	3.9	3.7
49.Y. 123	10 (250)	8 (210)	50 (1200)	48 (1300)	4.2	3.8
49.Y. 170	4 (120)	6 (190)	47 (1400)	55 (1700)	3.4	3.1
49.Y. 183	10 (280)	6 (190)	42 (1100)	35 (1000)	3.7	3.5
Average.....	6 (180)	6 (180)	49 (1320)	52 (1510)	3.7	3.5

(a). ABIES LASIOCARPA (Alpine Fir)

Comparison between Tips (Buds) and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Tips	Stems	Tips	Stems	Tips	Stems
49.81	6 (250)	7 (220)	35 (1300)	48 (1400)	2.6	3.3
49.92	4 (170)	4 (170)	21 (890)	32 (1200)	2.3	2.7
49.94	4 (170)	6 (250)	30 (1300)	41 (1600)	2.4	2.6
49.96	6 (210)	8 (280)	32 (1100)	47 (1700)	2.8	2.8
49.97	9 (300)	Lost	39 (1300)	46 (1600)	3.0	2.9
Average.....	6 (220)	6 (230)	31 (1200)	43 (1500)	2.6	2.9

(b). ABIES LASIOCARPA (Alpine Fir)
Copper, Zinc, and Ash Content of some Positive (Copper) Tips

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49.45	10 (340)	36 (1200)	3.1	0.29
49.71	10 (370)	27 (950)	2.8	0.39
49.72	13 (430)	40 (1300)	3.1	0.34
49.73	9 (310)	30 (1100)	2.9	0.30
49.80	8 (310)	35 (1400)	2.5	0.23
Average	10 (350)	34 (1200)	2.9	0.31

(c). ABIES AMABILIS (Balsam fir)
Comparison between Tips (Buds) and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Tips	Stems	Tips	Stems	Tips	Stems
49.70	8 (310)	6 (280)	21 (810)	31 (1400)	2.6	2.3
49.76	6 (240)	6 (260)	27 (1000)	38 (1500)	2.7	2.5
49.78	5 (250)	5 (220)	21 (1100)	32 (1400)	2.0	2.3
49.81	4 (200)	4 (180)	20 (890)	29 (1200)	2.2	2.5
49.92	5 (190)	6 (210)	26 (730)	31 (1100)	2.6	2.7
Average	6 (240)	5 (230)	23 (910)	32 (1300)	2.4	2.5

(d). ABIES AMABILIS (Balsam fir)
Copper, Zinc, and Ash Content of some Positive (Copper) Tips

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49. 43	8 (260)	34 (1000)	3.3	0.25
49. 61	6 (380)	14 (880)	1.6	0.43
49. 65	8 (260)	17 (570)	3.0	0.46
49. 71	9 (310)	25 (810)	3.1	0.38
49. 72	13 (430)	31 (1000)	3.0	0.42
49. 80	8 (310)	35 (1400)	2.5	0.23
49.106	10 (360)	34 (1200)	2.7	0.29
Average	9 (330)	27 (980)	2.7	0.35

large lake near where many of the samples were taken.

(b) *Abies amabilis* (Douglas) Forbes *Amabilis* Fir

Abies amabilis is also known as Red fir, lovely fir, alpine fir, larch, silver fir, white fir, balsam fir, and Cascade fir. This species extends from Oregon to southern Alaska in the coastal region. It is mostly confined to the western slope of the Coast Range and Vancouver Island but is found on the eastern margin of the Coast Range. *Abies amabilis* favors lower slopes and benches and grows on well-drained, gravelly sand, or sandy loams.

We know little about this species except that wherever *Abies amabilis* and *Abies lasiocarpa* are found in the same vicinity analyses have revealed a great similarity in the mineral content of the two species.

Table 21 (c) compares tips and stems bearing them. Table 21 (d) gives the ash contents of some weakly positive copper tips. The similarity

between the results appearing in these tables and those given in Tables 21 (a) and (b) is so striking that it seems safe to assume that these two species can be used interchangeably in biogeochemistry.

B. The Angiospermae

General Considerations

We have not been able to investigate the Angiospermae as thoroughly as we have the Gymnospermae, largely because fewer positive suites were available for collection during our preliminary investigations.

TABLE 22.—*SALIX* SP. (WILLOW)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48. 1	15 (160)	17 (300)	200 (1800)	164 (2800)	9.2	5.7
48. 8	16 (250)	13 (160)	90 (1300)	92 (1100)	6.6	8.3
48.10	11 (150)	4 (80)	145 (2000)	115 (2300)	7.3	4.8
48.13	10 (150)	15 (310)	84 (1200)	102 (2100)	6.8	4.8
49. 1	11 (190)	14 (180)	37 (630)	45 (590)	5.9	7.6
49. 2	12 (210)	12 (200)	74 (1300)	108 (1800)	5.7	6.1
49. 3	11 (160)	9 (110)	54 (790)	38 (430)	6.8	8.8
49.10	11 (130)	19 (400)	224 (2600)	156 (3300)	8.6	4.7
49.11	14 (170)	11 (140)	110 (1300)	68 (820)	8.2	8.3
49.17	13 (130)	17 (220)	80 (800)	114 (1500)	10.0	7.6
49.19	13 (190)	14 (270)	256 (3600)	174 (3300)	7.2	5.2
48.U.501	7 (230)	6 (310)	103 (4100)	200 (10000)	3.2	1.9
48.U.502	7 (160)	7 (250)	120 (2900)	140 (5400)	4.1	2.6
Average.....	12 (180)	12 (230)	120 (1870)	120 (2730)	6.9	5.9

In our previous publications we have suggested that the Cu:Zn ratio always be noted. In Tables 21 (b) and (d) the Cu:Zn ratio in many cases suggests anomalous conditions even where the absolute amount of copper does not.

(c) *Abies grandis* (Douglas) Lindley
Grand Fir

Abies grandis has a host of names including Lowland fir, white fir, western balsam, silver fir, larch, giant fir, lowland white fir. It is more limited in its range than the two species described above and is found only in the coastal and interior wet belts of southern British Columbia, Washington, and Oregon, and in the wet belts of Idaho and western Montana. It prefers deep, moist, but well-drained alluvial soils and may be found chiefly along streams and lower slopes.

No systematic collections of this species have been made, but the few analyses we have suggested that it conforms with the general pattern exhibited by *Abies lasiocarpa* and *Abies amabilis*.

One of the most important problems facing one wishing to use the Angiospermae in biogeochemical work is the difficulty of identifying the species of tree at the time of sampling. Several dozen varieties of *Salix* exist in the Pacific Northwest, and it is virtually impossible to identify them unless fruit is available, which is during a relatively short period each year. Further work may show that species identification will not be of vital importance, or perhaps important only in the case of genera possessing a wide variety of species such as the willows.

If such genera as *Salix* be excluded, different species within each genus appear to have similar response to mineralization. Such is not the case with the different families of Angiospermae any more than it is with the families of the Gymnospermae. The genus *Betula* and the genus *Alnus*, although both Betulaceae, appear to have little in common with respect to their selective absorption of trace elements.

Recent work by Lakin and Stevens (1949)

TABLE 23.—*SALIX* SP. (WILLOW)

Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash Per cent		
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	1st Yr.	2nd Yr.	3rd Yr.
48.14	16 (260)	10 (380)		70 (1100)	48 (1800)		6.1	2.6	
48.15	9 (210)	12 (470)		60 (1400)	74 (2900)		4.2	2.5	
48.16	8 (150)	5 (140)		72 (1300)	50 (1400)		5.4	3.4	
48.17	8 (240)	7 (260)		109 (3300)	108 (4500)		3.3	2.7	
48.19	10 (250)	6 (220)		66 (1600)	50 (1800)		4.0	2.7	
49. 1(a)	14 (180)	10 (300)		45 (590)	33 (930)		7.6	3.5	
49. 1(b)	9 (96)	5 (210)		33 (350)	40 (1500)		9.4	2.6	
49. 2	12 (200)	7 (250)	6 (220)	108 (1800)	75 (2500)	72 (2600)	6.1	3.0	2.8
49. 3	9 (110)	5 (190)	3 (140)	38 (430)	33 (1200)	26 (1200)	8.8	2.6	2.2
49. 4	10 (260)	7 (260)	5 (250)	28 (740)	24 (890)	22 (1100)	3.8	2.7	2.0
49. 5	7 (180)	5 (230)		43 (1100)	41 (1700)		3.8	2.4	
49. 6	20 (480)	8 (380)		130 (3100)	69 (3300)		4.2	2.1	
49. 7	4 (67)	8 (390)		148 (2500)	80 (3900)		6.0	2.0	
49. 8	13 (210)	5 (210)		118 (1900)	98 (3800)		6.3	2.6	
49. 9	6 (120)	5 (220)		144 (2900)	112 (4900)		5.0	2.3	
49.10	19 (400)	7 (340)		156 (3300)	109 (5400)		4.7	2.0	
49.11	11 (140)	8 (230)		68 (820)	48 (1300)		8.3	3.6	
49.17	17 (220)	9 (240)		114 (1500)	88 (2200)		7.6	4.0	
49.19	14 (270)	8 (320)		174 (3300)	144 (5800)		5.2	2.5	
49.20	12 (280)	6 (300)		114 (2500)	80 (3700))		4.5	2.1	
49.27	8 (240)	7 (290)		78 (2200)	105 (4300)		3.5	2.4	
48.U.501	6 (310)	7 (420)		200 (10000)	190 (12000)		1.9	1.5	
48.U.502	7 (250)	6 (330)		140 (5400)	130 (6600)		2.6	1.9	
Average.....	11 (220)	7 (290)	5 (200)	98 (2310)	80 (3400)	40 (1630)	5.3	2.6	2.3

(a). SALIX SP. (Willow)

Comparison between the Copper, Zinc, and Ash Contents of Willow Leaves,

(b). SALIX SP. (Willow)

Comparison between Copper, Zinc, and Ash Contents of young Willow

(a). SALIX SP. (Willow)

Comparison between the Copper, Zinc, and Ash Contents of Willow Leaves, Sullivan Area, B. C.

Sample No.	Copper	Zinc	Ash %	Cu:Zn
46.2	12 (200)	300 (4800)	6.2	0.040
46.14 Group 3	12 (280)	460 (11000)	4.3	0.027
46.19	2 (30)	460 (7600)	6.0	0.004
46.21	8 (140)	640 (10500)	6.1	0.013
Average.....	8 (160)	460 (8500)	5.6	0.020
46.9	8 (250)	800 (24000)	3.4	0.01
46.11	9 (190)	900 (18000)	4.9	0.01
46.13	11 (170)	370 (6000)	6.2	0.03
46.17	7 (110)	160 (2600)	6.1	0.04
46.23 Group 4(a)	6 (120)	380 (7400)	5.2	0.02
46.24	2 (30)	1100 (16000)	6.2	0.02
46.27	9 (150)	740 (12000)	3.1	0.01
46.29	8 (100)	860 (11000)	7.6	0.01
46.42	5 (110)	170 (3600)	4.9	0.03
Average.....	7 (140)	610 (11200)	5.3	0.02
46.31	6 (100)	1000 (18000)	5.6	0.01
46.32	8 (140)	860 (15000)	5.6	0.01
46.36 Group 4(b)	9 (160)	800 (13000)	6.0	0.01
46.38	9 (170)	500 (8800)	5.6	0.02
46.40	7 (130)	500 (9000)	5.6	0.01
Average.....	8 (140)	730 (12800)	5.7	0.01

(b). SALIX SP. (Willow)

Comparison between Copper, Zinc, and Ash Contents of young Willow Stems, Tweedsmuir Park Area, B.C.

Sample No.	Copper	Zinc	Ash %	Cu:Zn
49.21*	21 (460)	104 (2300)	4.6	0.20
49.22	6 (170)	33 (960)	3.5	0.18
49.23	15 (450)	65 (2000)	3.3	0.23
49.29*	26 (460)	110 (1900)	5.7	0.24
49.30*	28 (620)	204 (4400)	4.6	0.14
49.45	17 (370)	80 (1700)	4.7	0.22
49.46*	14 (310)	168 (3600)	4.7	0.08
49.61	17 (390)	56 (1300)	4.4	0.30
49.72	24 (590)	66 (1600)	4.1	0.36
49.98*	15 (480)	140 (4400)	3.2	0.11
Average....	18 (430)	103 (2400)	4.3	0.20

* This sample or the suite from this area may be zinc positive.

has promoted interest in any attempt to assess the relative reliability of stems and leaves for biogeochemical work. If stems are more, or even as, reliable as leaves the possibility of collecting and carrying out biogeochemical investigations on frozen and snow-covered ground will be greatly enhanced.

Tables 22–48 deal chiefly with comparisons between the copper, zinc, and ash content of leaves and stems bearing them, and of stems of different ages.

Family SALICACEAE

Genus *Salix*

Although *Salix amygdaloides* and *Salix sitchensis* have probably provided us with more samples than any other species we have had to lump all species together in a general presentation of this genus.

In Table 22 the copper, zinc, and ash contents of a collection of negative willows are compared. Wide and at first sight disheartening variations are immediately apparent. Similarly in Table 23 we find many deviations from any general rule. However, the following general relationships appear to justify their assumption if only as working hypotheses:

In general the copper, zinc, and particularly the ash contents of twigs decrease markedly during the first 3 years. Resulting in part from the decreased ash content the amount of both copper and zinc in ash increases in the second year over the first year. The copper and zinc do not vary proportionately, and thus we may infer that the two elements act independently.

There is no marked difference between the copper and the zinc content of dry plant material, but the stems tend to carry more copper and more zinc in their ash than do the leaves. Leaves average higher in ash than stems.

On the assumption that 1 full year's growth is more apt to reflect the mineral content of the soil than is the growth of a shorter period we now suggest that young leaves or stems are less likely to be accurate guides than stems of 1 full year's growth.

As a working hypothesis we suggest the following as normal for *Salix* sp.:

	Copper	Zinc	Ash per cent	Cu:Zn
Leaves	12(180) ± 50%	120(1800) ± 30%	6.8	.10
Young stems	12(220) ± 50%	120(2200) ± 30%	5.6	.10
Stems (1 year's growth)	7(270) ± 50%	80(3100) ± 30%	2.6	.09

We have three groups of zinc-positive willow leaves, all from the Sullivan area (Table 23 (a)). The details concerning these samples have already been given (Warren and Delavault, 1949).

We have no samples of willow from strongly copper-positive areas. Some results recorded in Table 23 are from areas which contain copper minerals but which show nothing approaching ore. However, we do have some young twigs taken during an exploration survey. These positive areas do not contain any mineralization which may be considered as ore now (1950), but they contain enough mineralization for future consideration. Table 23 (b) gives these results.

If Tables 22 and 23 are examined it will probably be agreed that willows leaves or stems may be useful in biogeochemical work. They have greater ranges for their normal content than many other trees, but in the future when the reasons for these variations are better understood we expect that willows will be widely used by biogeochemists. Its relatively rapid growth, its widespread root systems, the ease with which samples can be collected, and its relatively high mineral content all are points in its favor. Willow is one of the genera which should repay further and more exhaustive studies.

Genus *Populus*

Two species of this genus are widespread in the Pacific Northwest—*Populus tremuloides* and *Populus trichocarpa*. We have examined many samples of both, and *Populus tremuloides* in particular shows promise of being of use to biogeochemists.

(a) *Populus tremuloides* Michaux
Trembling Aspen, Poplar

This species also is known as asp, quaking asp, aspen poplar, white poplar, popple, and

smooth-barked poplar. Except for the coastal areas of British Columbia this species is common in most parts of the Pacific Northwest that provide reasonable growing conditions. It grows best on well-drained loam but it does grow on a wide variety of soils. However, it is intolerant of dense shade. It multiplies quickly and easily by means of root suckers and it may come in rapidly on new burns.

Populus tremuloides deserves extended study. It is well known, it is widespread, and it can be recognized and collected in winter almost as readily as in summer. Furthermore except for the willows and birches it is apparently the species most susceptible to zinc. Boron and zinc deficiencies are known to occur in the same area, and it may be that the rotten and evil-smelling cores of many individual poplars are caused by a deficiency of one or both of these elements.

Until recently we have considered this species to possess one great handicap for the biogeochemist: it is, in some areas, much slower growing than many of the species associated with it. Fortunately, as can be seen by Table 25, there appears to be much less difference in the copper, zinc, and ash content of first- and second-year stems of poplar than there is in the first- and second-year stems of most of the other common species. If this be established as a fact then poplar stems of 2 years' growth may be collected as general practice. Because the annular rings marking growth are conspicuous it should be easy to collect uniform samples. Furthermore, poplar ash may carry close to 1 p.p.m. of gold, an amount exceeded only by willow ash. We have no collections of poplar taken over strongly positive areas of either copper or zinc. However, occasional specimens taken from weakly positive areas suggest that poplar may respond to either element.

Tables 24 and 25 indicate the mineral and ash content of leaves and variously aged stems of this species. The decreasing copper and zinc content of dry-plant material and the increasing ash content of copper and zinc is to be noted.

TABLE 24.—*POPULUS TREMULOIDES* (TREMBLING ASPEN, POPLAR)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48.10	21 (330)	7 (140)	64 (1000)	57 (1100)	6.5	5.1
49. 2	18 (270)	11 (200)	130 (1900)	128 (2200)	6.8	5.8
49. 3	14 (180)	10 (160)	168 (2100)	133 (2200)	7.8	6.1
49.11	11 (160)	11 (190)	141 (2000)	97 (1700)	7.0	5.7
49.13	17 (190)	16 (210)	99 (1100)	87 (1100)	9.1	7.7
49.17	9 (150)	12 (270)	121 (2000)	112 (2500)	6.1	4.5
Average.....	15 (210)	11 (195)	120 (1680)	102 (1800)	7.2	5.8

As a working hypothesis we suggest the following as normals:

	Copper	Zinc	Ash per cent	Cu: Zn
Leaves.....	15(230) ± 50%	120(1800) ± 30%	6.5 ± 50%	.12
Stems (1st Yr.)....	12(220) ± 50%	94(1700) ± 30%	5.5 ± 50%	.13
Stems (2nd Yr.)....	9(250) ± 50%	60(1700) ± 30%	3.6 ± 50%	.15

(b) *Populus trichocarpa* Torrey and Gray Black Cottonwood

Also known as balsam cottonwood, balm cottonwood, western balm, western balsam, and western balsam poplar, this species is found throughout the Pacific Northwest in river-bottom lands. It is very intolerant of shade and normally can survive in mixed stands only if its more rapid growth enables it to keep ahead of other species. The authors have found it growing at the top of a 7000-foot ridge in southern British Columbia.

TABLE 25.—*POPULUS TREMULOIDES* (TREMBLING ASPEN, POPULAR)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.]	1st Yr.	2nd Yr.	3rd Yr.
48.16	11 (230)	6 (180)		55 (1100)	49 (1300)		4.8	3.7	
48.18	7 (130)	7 (180)		88 (1700)	74 (1900)		5.3	3.8	
48.19	11 (220)	11 (370)		49 (990)	51 (1700)		5.0	3.0	
49. 1	14 (210)	13 (240)	14 (220)	61 (910)	45 (820)	46 (720)	6.7	5.5	6.4
49. 2	11 (200)	7 (210)	6 (170)	128 (2200)	80 (2400)	83 (1700)	5.8	3.3	3.9
49. 3	10 (160)	12 (290)	12 (320)	133 (2200)	82 (1900)	76 (1900)	6.1	4.2	3.9
49. 5	12 (250)	11 (400)		71 (1400)	57 (2100)		5.1	2.7	
49.11	11 (190)	9 (240)		97 (1700)	55 (1500)		5.7	3.7	
49.13	16 (210)	7 (220)	8 (250)	87 (1100)	44 (1300)	47 (1400)	7.7	3.4	
49.14	16 (300)	13 (400)		93 (1700)	57 (1700)		5.5	3.4	3.4
49.17	12 (270)	8 (230)		112 (2500)	59 (1700)		4.5	3.4	
49.27	8 (270)	6 (230)		62 (1900)	51 (1900)		3.2	2.6	
Average.....	12 (220)	9 (270)	10 (240)	86 (1620)	59 (1680)	63 (1430)	5.4	3.6	4.4

The data in Tables 26 and 27 are far too skimpy to permit any satisfactory generalizations, and as we have no samples of satisfactory copper or zinc anomalous material we hesitate to draw any conclusions about normals. However, a much greater number of first-year stems were collected during the summer of 1949, and on the basis of the results obtained from these samples it is suggested that the copper and zinc contents of some of the samples in Tables 26 and 27 are lower than average. The normal copper and zinc content of *Populus trichocarpa*, therefore, probably more closely approximates that of *Populus tremuloides* than the tables indicate.

All the specimens numbered U come from Ungava where they were collected by Dr. J. Rousseau.

TABLE 26.—*POPULUS TRICHOCARPA* (COTTONWOOD)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48.13	12 (110)	6 (80)	160 (1300)	65 (910)	12.2	7.1
49.11	10 (120)	11 (130)	108 (1300)	86 (1000)	8.1	8.6
Average.....	11 (115)	8 (105)	130 (1300)	75 (950)	10.1	7.8

TABLE 27.—*POPULUS TRICHOCARPA* (COTTONWOOD)
Comparison between Stems of Different Ages

Sample No.	Copper		Zinc		Ash Per cent	
	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.
48.17	11 (190)	9 (210)	69 (1200)	68 (1600)	5.5	4.2
49. 4	6 (95)	4 (80)	31 (480)	40 (710)	6.4	5.6
49.11	11 (130)	3 (70)	86 (1000)	68 (1600)	8.6	4.2
49.20	7 (130)	4 (170)	120 (2100)	90 (3800)	5.8	2.4
49.54	18 (260)	7 (240)	110 (1600)	63 (2000)	7.0	3.1
Average.....	11 (160)	5 (150)	80 (1280)	66 (1940)	6.7	3.9

Family BETULACEAE

Genus *Betula*

Rather than omit this important genus we present the available information in the belief that the results will be of value, especially when we can say that all our other results substantiate the general conclusions arrived at in Tables 28 to 33.

(a) *Betula glandulosa* (Michaux) Scrub Birch

This species, which incidentally is found in suitable habitats all across Canada, is widespread throughout the Pacific Northwest especially in subalpine meadows where it is in many instances the only deciduous species of shrub found.

Usually it is of slow growth and normally would not be favored by a biogeochemist. However, this species seems to be peculiarly susceptible to zinc, and as such it may prove to be very useful in exploration biogeochemistry.

Tables 28 and 29 indicate clearly the most interesting features of this species. All the samples are from areas believed to be copper and zinc negative, consequently it would be unwise to hazard a guess as to what might be expected in anomalous samples. It seems hard to believe that sample 48.U 918 has a normal zinc content and possibly that area should be investigated!

If the ash content be considered it may be noted that for both copper and zinc the stems are richer than the leaves they bear, and the second-year stems are richer than the first-year stems.

The two samples presented in Tables 32 and 33 would not be worth mentioning were it not that we had more data which indicate the tendency of this species to be high in zinc. These data are not yet available for release.

TABLE 28.—*BETULA GLANDULOSA* (SCRUB BIRCH)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
49.10	10 (210)	9 (330)	216 (4600)	165 (5700)	4.7	2.9
49.19	12 (240)	11 (430)	240 (4600)	155 (5700)	5.2	2.7
48.U. 499	7 (270)	7 (440)	65 (2500)	85 (5300)	2.6	1.6
48.U. 918	8 (260)	6 (370)	216 (7000)	230 (14000)	3.1	1.6
48.U.1077	7 (190)	7 (460)	140 (3800)	100 (7100)	3.7	1.4
48.U.1457	16 (570)	9 (640)	160 (5900)	36 (2600)	2.7	1.4
48.U.1565	9 (270)	7 (390)	158 (5100)	148 (8200)	3.1	1.8
Average.....	10 (290)	8 (440)	170 (4800)	130 (6940)	3.6	1.9

(b) *Betula occidentalis* Hooker Red Birch

This species is widespread in the Pacific Northwest east of the Coast Range Mountains and south of headwaters of the Fraser and Peace rivers.

It is also called mountain birch, black birch, and water birch and has also gone by the scientific name of *Betula fontinalis* (Sargent).

Betula occidentalis is chiefly found on moist soils along streams and around springs. It may be found in pure stands, but it is more often mixed with alders, cottonwoods, and willows.

The scanty evidence presented in Tables 30 and 31 indicate that *Betula occidentalis* like *Betula glandulosa* has a liking for zinc and tends to have a normal zinc content higher than that found in species of any other genus.

(c) *Betula papyrifera* (Marshall)
Western White Birch

This species is also known as birch, silver birch, western birch, British Columbia birch, black birch, and white birch. The name "Western White" is misleading as the tree is also found in Eastern Canada. In Canada it occurs only in southern British Columbia but extends southward into the neighboring States.

Genus *Alnus*

In the Pacific Northwest four species of this important genus are of interest to biogeochemists—*Alnus sinuata*, *Alnus rubra*, *Alnus rhombifolia*, and *Alnus tenuifolia*. We have concentrated on *Alnus sinuata*. However, we have collected enough data to enable us to conclude that the other alders have the same biogeochemical characteristics as *Alnus sinuata*.

(a) *Alnus sinuata* (Regel) Rydberg
Sitka Alder

This species is also known as green alder, northern alder, and mountain alder; furthermore, it has been described by the scientific name of *Alnus sitchensis* (Regel) Sargent.

Probably this will prove to be one of our more useful trees from the point of view of the biogeochemist. It extends from the Arctic Circle to California and from the Pacific Coast to the Rocky Mountains. It favors moist bottoms and marshy flats and in places forms a formidable obstacle to those who attempt to penetrate slide areas in the Coast Range Mountains.

Tables 34 and 35 represent all the information available to use on leaves and twigs of various ages.

TABLE 29.—*BETULA GLANDULOSA* (SCRUB BIRCH)
Comparison between Stems of Various Ages

Sample No.	Copper			Zinc			Ash Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49. 6	10 (350)	5 (320)		160 (5300)	139 (8600)		3.0	1.5	
49. 9	8 (250)	13 (760)		188 (5600)	180 (11000)		3.3	1.7	
49.10	9 (330)	5 (330)		165 (5700)	158 (11000)		2.9	1.5	
49.16	4 (120)	6 (400)		162 (5200)	110 (7300)		3.1	1.5	
49.17	12 (410)	7 (440)		116 (3900)	88 (5200)		3.0	1.7	
49.19	11 (430)	7 (520)	6 (480)	155 (5700)	144 (10000)	155 (12000)	2.7	1.4	1.2
48.U. 499	7 (440)	8 (530)		85 (5300)	103 (6900)		1.6	1.5	
48.U. 918	6 (370)	5 (440)		230 (14000)	390 (23000)		1.6	1.2	
48.U.1077	7 (460)	5 (500)		100 (7100)	130 (13000)		1.4	1.0	
48.U.1457	9 (640)	5 (550)		36 (2600)	140 (14000)		1.4	1.0	
48.U.1565	7 (390)	6 (480)		148 (8200)	164 (12100)		1.8	1.3	
Average.....	8 (380)	7 (480)	6 (480)	140 (6240)	160 (11100)	155 (12000)	2.3	1.4	1.2

The main conclusions we believe tenable are: alders are readily susceptible to copper—witness sample 48.19—and somewhat less susceptible to zinc than the genera *Populus*, *Salix*, or *Betula*. In a previous paper (Warren and Delavault, 1948) a comparison was made between the zinc content of twigs of *Alnus rubra* and *Salix* sp. growing on identical ground. In all cases the zinc content of *Alnus rubra* was well below that of the willow.

During the 1949 field season nearly 100 samples of tips of young stems of *Alnus sitchensis* were collected, and the average for these young tips was as follows:

	Copper	Zinc	Ash per cent	Cu:Zn
1st Yr. tips..	9(330) ± 50%	30(1000) ± 30%	3%	.30

We stated (Warren, Delavault, and Irish, 1949) that on the basis of the evidence available for *Alnus rubra* a copper content of more than 10 p.p.m. dry-plant material and a copper to zinc ratio of greater than .40 might be considered anomalous. All this indicates that in general alders are relatively more responsive to copper than they are to zinc. Originally we considered that this zinc deficiency might be caused not by the tree but by the soil from which the tree was feeding. However, the fact that willows growing in close proximity to the alders consistently carried greater quantities of zinc suggests that the alders do not favor zinc.

During the 1949 field season a large number of young stems of *Alnus sitchensis* were collected, and a few samples were from weakly positive zinc and copper suites. A few of these results are given in Tables 35 (a), (b), and (c).

TABLE 30.—*BETULA OCCIDENTALIS* (MOUNTAIN, RED, OR WATER BIRCH)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48.2	15 (270)	4 (85)	34 (610)	23 (490)	5.6	4.7
49.2	8 (110)	8 (120)	120 (1600)	130 (2000)	7.6	6.6
49.3	11 (150)	15 (170)	127 (1800)	168 (2000)	7.1	8.6
Average....	11 (180)	9 (125)	94 (1340)	110 (1500)	6.8	6.6

TABLE 31.—*BETULA OCCIDENTALIS* (MOUNTAIN, RED, OR WATER BIRCH)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash, Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.2	8 (120)	6 (210)		130 (2000)	124 (4200)		6.6	2.9	
49.3	15 (170)	6 (310)	2 (150)	168 (2000)	75 (3600)	46 (2700)	8.6	2.1	1.7
Average...	11 (145)	6 (260)	2 (150)	150 (2000)	100 (3900)	46 (2700)	7.6	2.5	1.7

TABLE 32.—*BETULA PAPYRIFERA* (SILVER OR WESTERN WHITE BIRCH)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48.10	12 (170)	6 (140)	213 (3000)	137 (3300)	7.0	4.2

TABLE 33.—*BETULA PAPYRIFERA* (SILVER OR WESTERN WHITE BIRCH)

Comparison between Stems of Different Ages

Sample No.	Copper		Zinc		Ash Per cent	
	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.
49.2	22 (260)	11 (410)	104 (1200)	65 (2500)	8.4	2.8

TABLE 34.—*ALNUS SINUATA* (GREEN, MOUNTAIN, OR SITKA ALDER)

Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
49.11	13 (180)	12 (250)	34 (470)	36 (700)	7.3	5.1

TABLE 35.—*ALNUS SINUATA* (GREEN, MOUNTAIN, OR SITKA ALDER)

Comparison between Stems of Different Ages

Sample No.	Copper		Zinc		Ash Per cent	
	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.	1st Yr.	2nd Yr.
48.18	7 (200)	5 (200)	27 (700)	28 (1100)	3.5	2.4
48.19*	10 (300)	9 (500)	23 (690)	23 (1300)	3.3	1.8
49.11	15 (250)	5 (200)	36 (700)	18 (670)	5.1	2.7
49.20	8 (200)	7 (260)	24 (570)	38 (1400)	4.2	2.7
49.27	5 (160)	5 (190)	24 (700)	24 (910)	3.4	2.6
49.54	7 (190)	5 (200)	30 (770)	17 (690)	3.9	2.4
Average.....	9 (220)	6 (260)	27 (690)	25 (1010)	3.9	2.4

(a). ALNUS SINUATA (Sitka Alder)

Copper, Zinc and Ash Content of some Normal Young Stems

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49.20	8 (200)	24 (570)	4.2	0.35
49.24	10 (370)	21 (780)	2.7	0.48
49.25	13 (400)	30 (870)	3.4	0.46
49.26	3 (100)	29 (940)	3.1	0.10
49.27	5 (160)	24 (700)	3.4	0.23
49.31	14 (370)	32 (810)	3.9	0.45
49.32	8 (230)	28 (800)	3.5	0.29
49.33	9 (300)	36 (870)	3.0	0.35
49.60	9 (300)	25 (780)	3.2	0.38
49.75	7 (210)	20 (570)	3.5	0.38
Average.....	9 (260)	27 (770)	3.4	0.35

* Sample known to be copper positive.

(b). ALNUS SINUATA (Sitka Alder)

Copper, Zinc, and Ash Content of some Weakly Copper Anomalous Young Stems

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49.22	10 (380)	31 (1100)	2.7	0.33
49.23	11 (500)	33 (1500)	2.2	0.33
49.36	13 (330)	27 (680)	4.0	0.48
49.37	13 (340)	32 (840)	3.8	0.41
49.39	12 (460)	34 (1300)	2.7	0.37
49.40	24 (630)	37 (950)	3.9	0.66
49.43	10 (300)	36 (1200)	3.3	0.26
49.45	12 (390)	30 (940)	3.2	0.42
49.61	10 (580)	33 (1800)	1.8	0.32
49.62	15 (520)	44 (1500)	3.0	0.35
Average.....	13 (440)	34 (1200)	3.1	0.39

(c). ALNUS SINUATA (Sitka Alder)

Content, Zinc, and Ash Content of some Weakly Zinc Anomalous Young Stems

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49.56	10 (440)	37 (1600)	2.3	0.27
49.64	12 (420)	41 (1400)	3.0	0.31
49.82	13 (580)	36 (1600)	2.2	0.36
49.86	11 (430)	37 (1400)	2.7	0.31
49.88	7 (300)	39 (1700)	2.3	0.18
49.100	16 (530)	42 (1400)	3.1	0.39
49.101	4 (160)	35 (1400)	2.5	0.11
49.103	6 (280)	39 (3000)	2.3	0.09
49.105	10 (390)	32 (1300)	2.5	0.31
49.112	11 (390)	40 (1400)	2.9	0.29
Average.....	10 (390)	38 (1600)	2.6	0.26

These results are not inspiring to a beginner, but when taken as a part of numerous suites they begin to fit into a pattern. These results illustrate the type of anomaly which may be encountered in exploration work. It would be impossible to miss a Sullivan or a Britannia if one got within a few hundred feet of them. Without careful study it would be useless to try to interpret the results given in Tables 35 (a), (b), and (c). In considering these three tables it is well to remember that in most areas in British Columbia it is usual to find small amounts of copper with zinc, and small amounts of zinc with copper. The localities from which these suites were collected represent no exception to this rule.

Family SAXIFRAGACEAE

We have collected data only on a single species belonging to this family—namely *Philadelphus Lewisii.*

Genus *Philadelphus*

Philadelphus Lewisii Pursh Syringa

The species extends all across the southern portion of British Columbia from the coast to the Rocky Mountains and carries on into the adjoining American States. It is also known as Mock Orange.

In spite of a woefully small number of available analyses and no anomalous samples it seems clear that this species has some distinc-

tive qualities. Its leaves have the highest ash content of any tree or lesser plant examined—if horsetails be excluded. Furthermore, in spite of its high ash content its leaves carry in their ash less copper and zinc than any other species examined. Furthermore, its stems are also high in ash and low in copper and zinc. This might well have been caused by regional deficiencies in the soil, but this possibility, although not ruled out as a contributory factor, is not the sole cause because other plants growing near by show neither such high ash contents nor such low copper and zinc in their ash (Tables 36, 37).

Solely as a working hypothesis we suggest the following as possible normals for leaves and stems bearing them:

	Copper	Zinc	Ash per cent	Cu:Zn
Leaves.....	8(60) ± 50%	23(170) ± 30%	13.9	.35
Stems bearing them..	7(100) ± 50%	34(480) ± 30%	7.5	.20
Second year stems.....	5(140) ± 50%	28(800) ± 30%	3.5	.18

TABLE 36.—*PHILADELPHUS LEWISII* (SYRINGA OR MOCK ORANGE)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48. 6	10 (65)	7 (90)	22 (140)	25 (330)	15.2	7.6
48. 7	11 (60)	10 (110)	25 (140)	36 (420)	18.0	8.6
48. 9	5 (45)	5 (130)	22 (200)	26 (660)	10.8	4.0
48.10	8 (50)	6 (100)	23 (140)	34 (650)	16.3	6.0
48.11	8 (60)	9 (140)	18 (130)	28 (440)	13.5	6.3
48.12	5 (50)	5 (60)	15 (140)	31 (350)	11.0	8.9
49. 2	9 (73)	10 (90)	33 (270)	56 (510)	12.3	11.0
Average....	8 (60)	7 (100)	23 (170)	34 (480)	13.9	7.5

TABLE 37.—*PHILADELPHUS LEWISII* (SYRINGA OR MOCK ORANGE)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash, Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.2	9 (70)	5 (150)	7 (200)	38 (280)	30 (900)	19 (510)	11.0	3.3	3.7

soils in open spaces. *Prunus demissa* may be found in small thickets along streams, highways, forest borders, and in small clearings.

Tables 38 and 39 represent pretty well the present state of our knowledge of this species. As a working hypothesis the averages given in Table 38 may be taken as normal.

Family ROSACEAE

GENUS *Prunus*

Prunus demissa Nuttall Choke Cherry

This species is widespread throughout the whole Pacific Northwest. However, it is relatively intolerant of shade and prefers rich moist

Genus *Amelanchier*

Amelanchier alnifolia Nuttall Saskatoon

This species has a range paralleling that of *Prunus demissa*. In general it has a lower ash content and a higher copper and zinc content in its ash than *Prunus demissa*, and Tables 40 and 41 summarize our information about this species.

TABLE 38.—*PRUNUS DEMISSA* (CHOKE CHERRY)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48. 4	8 (80)	9 (130)	22 (220)	46 (680)	10.0	6.7
48. 5	9 (180)	8 (160)	30 (610)	27 (550)	4.9	3.6
48. 6	12 (110)	8 (160)	17 (150)	17 (330)	11.0	5.2
48. 7	15 (190)	3 (100)	49 (610)	18 (570)	8.1	3.1
48. 8	9 (90)	5 (70)	23 (240)	36 (470)	9.6	7.6
48. 9	9 (80)	9 (200)	18 (160)	32 (720)	11.0	5.0
48.11	10 (70)	5 (90)	26 (190)	38 (670)	14.0	5.6
48.12	6 (60)	6 (90)	16 (150)	68 (1100)	10.4	6.3
49. 2	8 (110)	9 (190)	23 (300)	32 (690)	7.5	4.7
49. 3	14 (220)	12 (230)	34 (520)	48 (870)	6.5	5.4
Average....	10 (120)	7 (140)	26 (315)	36 (665)	9.3	5.3

TABLE 39.—*PRUNUS DEMISSA* (CHOKE CHERRY)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash, Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.2	9 (190)	7 (140)	6 (160)	32 (690)	16 (300)	11 (310)	4.7	5.4	3.7
49.3	12 (230)	8 (290)	6 (300)	48 (870)	18 (620)	13 (650)	5.4	2.9	2.0
Average...	10 (210)	7 (215)	6 (230)	40 (780)	17 (460)	12 (480)	5.0	4.1	2.8

TABLE 40.—*AMELANCHIER ALNIFOLIA* (SASKATOON)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48. 2	10 (130)	4 (90)	20 (270)	17 (370)	7.5	4.6
48. 3	10 (200)	7 (290)	36 (730)	38 (1600)	4.9	2.4
48. 4	19 (210)	7 (160)	25 (270)	20 (470)	9.2	4.2
48. 5	12 (160)	5 (150)	17 (220)	19 (560)	7.7	3.4
48. 6	12 (150)	3 (110)	17 (220)	16 (580)	7.9	2.7
48. 7	16 (190)	5 (140)	40 (600)	25 (720)	7.4	3.4
48. 8	11 (140)	5 (110)	35 (440)	36 (760)	8.0	4.7
48. 9	7 (110)	4 (130)	35 (530)	40 (1300)	6.6	3.0
48.10	14 (160)	8 (300)	48 (510)	37 (1300)	9.0	2.7
48.11	10 (160)	5 (150)	26 (430)	26 (720)	6.3	3.6
48.12	10 (160)	3 (110)	25 (410)	20 (740)	6.1	2.7
49. 2	8 (83)	10 (190)	49 (500)	52 (960)	9.7	5.4
49. 3	7 (84)	16 (240)	23 (260)	37 (540)	8.9	6.9
49.11	14 (160)	13 (220)	41 (460)	40 (690)	8.9	5.8
Average.....	11 (150)	7 (170)	31 (420)	30 (810)	7.7	4.0

We have one zinc-positive sample of *Amelanchier alnifolia*, as follows:

	Copper	Zinc	Ash per cent	Cu:Zn
Leaves	5(60)	30 (350)	5.6	.17
Stems bearing them	Not available	71((2000)	3.6	Not available

Alaska southward along the Pacific Coast. Below about Lat. 51° N. it extends eastward to Alberta and southward throughout the area under consideration. It grows on thin usually gravelly soil along gulches, mountain streams, cliffs, and canyon sides. As these are just the localities where prospecting may be difficult

TABLE 41.—*AMELANCHIER ALNIFOLIA* (SASKATOON)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash, Per cent		
	1st Yr.	2nd Yr.	3rd Yr	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.1	16 (250)	4 (140)	3 (160)	39 (590)	15 (520)	12 (560)	6.5	2.8	2.2
49.2	10 (190)	5 (200)	3 (170)	52 (960)	50 (1800)	31 (1500)	5.4	2.8	2.1
49.3	16 (240)	8 (330)	7 (350)	37 (540)	33 (1400)	28 (1400)	6.9	2.4	2.0
49.4	10 (240)	6 (180)	3 (83)	41 (1000)	33 (1000)	30 (830)	4.1	3.2	3.6
49.11	13 (220)	8 (250)		40 (690)	21 (670)		5.8	3.1	
49.27	5 (160)	4 (240)		24 (760)	15 (910)		3.1	1.6	
Average...	12 (220)	6 (220)	4 (190)	39 (760)	28 (1050)	25 (1070)	5.3	2.6	2.5

TABLE 42.—*ACER GLABRUM* (MOUNTAIN MAPLE)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48. 1	11 (150)	8 (170)	45 (600)	28 (600)	7.5	4.7
48. 2	13 (190)	2 (40)	17 (250)	16 (310)	6.9	5.2
48. 8	11 (160)	4 (110)	35 (510)	14 (390)	6.9	3.6
48.11	10 (150)	2 (50)	24 (360)	26 (630)	6.7	4.1
49. 2	16 (180)	12 (110)	25 (290)	29 (260)	8.6	11.0
49. 3	16 (180)	11 (100)	42 (470)	31 (290)	8.8	10.6
Average.....	13 (170)	6 (100)	31 (410)	24 (410)	7.6	6.5

This suggests that stems may be better indicators than leaves, but we suggest that any such conclusions be withheld pending more data.

Family ACERACEAE

Genus *Acer*

Acer glabrum Torrey
Rocky Mountain Maple

This tree variously known as dwarf maple, red maple, and mountain maple is found from

owing to lack of outcrops further work on this species is needed because we have no examples of either zinc or copper anomalous samples.

Tables 42 and 43 present the information on this species. Some of the evidence may appear contradictory, but in general probably *Acer glabrum* represents a fair medium of the species which we have studied, in that it is neither strikingly high nor low in its ash, copper, or zinc contents, or in the copper to zinc ratio.

Family Araliacea

Genus *Echinopanax*

Echinopanax horridus Devil's Club

Formerly classed as *Fatsia horrida* (Bentham and Hooker) this species has long been the bane of all who had to traverse areas in which it was conspicuous. Apparently it can thrive where there is abundant moisture and not too great cold; it attains its most luxuriant growth on the western slopes of the Coast Range Mountains.

It seemed to us that if this ill-favored plant could be put to any use our labors would not have been in vain. It carries more than 1 per cent of copper in the ash of its leaves in a copper-positive area and a bare 300 p.p.m. in a near-by negative area.

us, so we have no idea what variations may be expected. The following normals are suggested:

	Copper	Zinc	Ash per cent	Cu:Zn
Leaves....	9(90) ± 50%	24(240) ± 30%	10.0	.37
1st Year stems...	9(130) ± 50%	30(430) ± 30%	7.0	.30
2nd Year stems...	6(170) ± 50%	18(410) ± 30%	3.5	.33

Family Compositae

Genus *Artemisia*

(a) *Artemisia tridentata* Nuttall Sage brush

This species and the closely associated *Artemisia trifida* are widespread throughout the

Table 43.—*ACER GLABRUM* (Mountain Maple)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash, Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.2	10 (110)	3 (140)	4 (250)	29 (260)	10 (490)	11 (610)	11.0	2.1	1.8
49.3	11 (100)	6 (230)	3 (150)	31 (290)	20 (680)	24 (980)	10.6	2.8	2.4
Average...	10 (105)	4 (185)	3 (200)	30 (275)	15 (585)	17 (795)	10.8	2.4	2.1

Table 44 tends to confirm the biogeochemical potentialities of this unpleasant species.

Family Caprifoliaceae

Genus *Symphoricarpos*

Symphoricarpos racemosus Michaux Wax Berry

This species is general throughout the Pacific Northwest and is also known as snow berry and broom bush.

Its ash content is relatively high, and its copper and zinc content relatively low: like all the Angiospermae we have studied, the leaves have a higher ash content than the stems which bear them. The ash of stems is slightly higher in zinc than the ash of the leaves they bear.

Tables 45 and 46 illustrate the available results. No anomalous samples are available to

dry interior of the Pacific Northwest. The obvious value of these bushes, if they could be used by a biogeochemist, prompted us to take a few samples. Not much may be assumed from the few available analyses. However, it seems clear that copper:zinc ratio is relatively high and that unless the copper:zinc ratio is greater than 1 the specimen need not be considered copper anomalous. The behavior of sage brush in zinc-anomalous ground is as yet unknown.

Table 47 presents some typical analyses of this species.

(b) *Artemisia trifida* Nuttall

The two analyses presented in Table 48 illustrate that this species of sage brush is apparently as sensitive to copper as is *Artemisia tridentata.*

In view of recent investigations in South Australia where desert conditions have been

TABLE 44.—*ECHINOPANAX HORRIDUS* (DEVIL'S CLUB)
Copper, Zinc, and Ash Content of some Normal 1st Year Stems

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49. 31	13 (160)	42 (520)	8.1	0.30
49. 32	12 (150)	35 (450)	7.8	0.34
49. 44	15 (200)	48 (650)	7.4	0.31
49. 48	15 (170)	58 (630)	9.1	0.27
49. 49	13 (220)	58 (940)	6.2	0.23
49. 50	11 (240)	14 (290)	4.8	0.82
49. 51	10 (110)	20 (210)	9.3	0.51
49. 75	11 (160)	38 (520)	7.2	0.31
49. 78	8 (140)	22 (350)	6.3	0.39
49. 79	18 (280)	46 (720)	6.4	0.39
Average	13 (180)	38 (530)	7.3	0.39

(a). ECHINOPANAX HORRIDUS (Devil's Club)
Copper, Zinc, and Ash Content of some Weakly Copper Anomalous 1st Year Stems

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49. 36	18 (220)	34 (400)	8.4	0.54
49. 37	15 (270)	38 (650)	5.8	0.41
49. 65	22 (190)	60 (520)	11.6	0.36
49. 80	18 (240)	53 (700)	7.6	0.35
49.106	16 (220)	51 (710)	7.2	0.31
Average	18 (230)	47 (600)	8.1	0.39

(b). ECHINOPANAX HORRIDUS (Devil's Club)
Copper, Zinc, and Ash Content of some Weakly Zinc Anomalous 1st Year Stems

Sample No.	Copper	Zinc	Ash Per cent	Cu:Zn
49. 56	14 (230)	53 (880)	6.0	0.26
49. 64	10 (150)	47 (690)	6.8	0.21
49. 86	11 (190)	57 (970)	5.9	0.19
49.100	10 (130)	70 (940)	7.4	0.14
49.101	12 (180)	57 (860)	6.6	0.21
49.105	11 (190)	50 (880)	5.6	0.22
49.112	10 (130)	66 (880)	7.5	0.15
Average	11 (170)	57 (870)	6.5	0.20

shown to have been caused in part by zinc and copper deficiencies, and remembering that zinc and copper deficiencies are highly probable in many areas of the Pacific Northwest it seems relevant to suggest that further studies of these sage brushes may prove very useful not only to prospectors but also to agriculturists.

SELECTION OF PLANT ORGANS

In selecting the organ of a plant to be used for a biogeochemical survey three main questions must be considered:

(1) Which organ can be most readily collected?

TABLE 45.—*SYMPHORICARPOS RACEMOSUS* (BROOM BUSH, SNOW OR WAX BERRY)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48. 4	14 (160)	17 (230)	19 (220)	25 (360)	8.8	6.9
48. 5	9 (70)	7 (80)	24 (190)	22 (260)	12.8	8.6
48. 6	10 (80)	6 (80)	26 (190)	22 (300)	13.1	7.4
48. 7	10 (110)	8 (110)	25 (270)	25 (360)	9.4	7.0
48. 8	8 (86)	7 (100)	31 (310)	61 (870)	9.9	7.0
48. 9	6 (50)	6 (120)	20 (170)	32 (620)	12.0	5.2
48.11	7 (83)	4 (90)	30 (350)	52 (1200)	8.6	4.3
48.12	5 (51)	3 (60)	18 (180)	21 (420)	9.7	5.0
49. 3	11 (100)	12 (110)	34 (290)	35 (320)	11.7	10.8
49.11	9 (120)	10 (160)	17 (220)	20 (340)	7.6	6.1
Average.....	9 (90)	8 (110)	24 (240)	31 (500)	10.4	6.8

TABLE 46.—*SYMPHORICARPOS RACEMOSUS* (BROWN BUSH, SNOW OR WAX BERRY)
Comparison between Stems of Different Ages

Sample No.	Copper			Zinc			Ash, Per cent		
	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.	1st Yr.	2nd Yr.	3rd Yr.
49.2	10 (140)	7 (150)	4 (120)	30 (420)	24 (510)	16 (450)	7.2	4.7	3.6
49.3	12 (110)	6 (150)	5 (180)	35 (320)	20 (510)	16 (600)	10.8	3.9	2.7
49.5	11 (210)	5 (190)		27 (490)	16 (540)		5.5	2.9	
49.11	10 (160)	6 (220)		20 (340)	10 (380)		6.1	2.6	
Average...	11 (155)	6 (180)	4 (150)	28 (390)	17 (485)	16 (525)	7.4	3.5	3.1

TABLE 47.—*ARTEMISIA TRIDENTATA* (SAGEBRUSH)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48. 3	10 (140)	8 (170)	19 (280)	17 (360)	6.9	4.7
48. 4	35 (330)	21 (250)	35 (330)	21 (250)	10.7	8.5
48. 5	10 (140)	17 (270)	37 (510)	20 (320)	7.3	6.3
48. 6	12 (90)	11 (90)	22 (170)	22 (180)	13.3	12.1
Average.....	17 (175)	14 (195)	28 (320)	20 (280)	9.5	7.9

(2) Which organ can be most easily analysed?

(3) Which organ responds most readily to anomalous conditions?

We do not yet have sufficient data to answer these questions with any degree of finality. We have, however, considerable experience on which to make some tentative suggestions, and we shall discuss briefly each question.

(1) Which organ can be most readily collected?

We have already discussed at some length why we do not consider roots, bark, wood, cones to be satisfactory in spite of their ease of availability (Warren and Delavault, 1949).

Leaves have much to commend them as

TABLE 48.—*ARTEMISIA TRIFIDA* (SAGEBRUSH)
Comparison between Leaves and Stems Bearing Them

Sample No.	Copper		Zinc		Ash Per cent	
	Leaves	Stems	Leaves	Stems	Leaves	Stems
48.12	12 (210)	8 (200)	36 (620)	25 (610)	5.8	4.1
48.50	30 (350)	19 (510)	35 (410)	29 (780)	8.5	3.7
Average.....	21 (280)	13 (355)	35 (515)	27 (695)	7.1	3.9

undoubtedly may be used successfully under favorable circumstances, such as when ashing is to be done shortly after collecting. Lakin and Reichen (1949) have shown how leaves may be used to advantage.

On the other hand leaves can be collected only during a portion of the season, and our experience suggests that the copper and the zinc content of leaves may vary considerably with the time of the season at which the sample is taken.

Needles, although they are available at all times of the year, are not easy to collect, and indeed in the case of the spruces and junipers they are bothersome if they are not dried thoroughly before they are plucked from the stem bearing them.

Young tips and buds of the evergreens are the easiest organs of all to collect, except in the early part of the growing season, when collecting a satisfactory sample may be wearying. In the case of some slow-growing species such as *Tsuga Mertensiana* prospectors loathe collecting this species and are apt to collect second-year material, accidentally, if not by design.

Young stems are often easy to collect, particularly late in the growing season.

With suitable collecting tools we have found that stems of one full season's growth are easy to gather, after a little practice, and have the advantage of being easier to deprive of their leaves or needles. These stems are easily prepared for shipping and do not mould as leaves may.

In short, although any organ can be collected readily, and tips or buds of evergreens perhaps most readily of all, stems of one full season's growth are probably the best organ on which to base any new investigation.

(2) Which organ can be most easily analysed? Second-year stems have a higher copper and zinc content in their ash, a lower overall ash content, and they ash more readily than any other organ we have been discussing. For these reasons we favor stems of one full season's growth. The numerous tables would seem overwhelmingly to favor this conclusion.

(3) Which organ responds most readily to anomalous conditions?

Much more statistical evidence must be collected before this question can be answered. However we do have some data on this question.

Obviously some very young tips of spruce are unreliable, and indeed the very young growth of any species seems most erratic, insofar as copper is concerned, although the pines possibly may not be so erratic as some of the other genera.

Some tips, notably those of *Thuja plicata*, appear to show very little response to abnormal zinc conditions.

On the other hand, provided that the tips or young buds have been well developed, we have found in some species, such as *Pseudotsuga taxifolia* and *Abies lasiocarpa*, that they are satisfactory, at least for reconnaissance work.

In short, until an area has been studied, tips are apt to be deceiving, but under some conditions in a known area tips may be most useful. Stems of one full season's growth, although they may not always show the spectacular, and sometimes puzzling, variations of leaves and other young organs, are probably the most reliable indicators of zinc and copper anomalies. Further statistical work should be presented before this premise is generally accepted.

Thus, in spite of some factors favoring younger organs we are now firmly convinced that, for most species of trees, stems of one full season's growth are the best organs for any preliminary biogeochemical investigation.

Notes on the Use of Biogeochemical Data

The present paper is largely concerned with fundamental information, which is needed before biogeochemical prospecting can be usefully initiated, and deals mostly with the copper and zinc contents of different young parts of many plant species. Most of the samples come from widely separated localities. Hampered as we have been by lack of funds, we have been quite unable to carry out any systematic field work such as would naturally have been most desirable. However, thanks to the support of various private companies, and particularly New Jersey Zinc Explorations, Limited, and the British Columbia International Engineering Company, Limited, extended field work has been made possible, and on the basis largely of this field work we can illustrate how the tables may be utilized in achieving the ultimate goal of all these biogeochemical researches—namely, the detection of ore through the systematic investigation of the metal content of vegetation.

We have described (Warren and Delavault, 1949) the metal content of trees from three richly mineralized areas. In such cases a glance at the analytical results was sufficient to ascertain which samples came from rich areas and which ones from barren places. In practice results are not so clear cut. We found that the normal metal contents ranged considerably from area to area largely because of variations in the climate, physiography, and underlying rock types.

At this point a biogeochemist searching for mineralization is faced with a dilemma. He must choose between two possible methods of attack. On the one hand he may take samples, as many as practical, and hope to stumble on one or two, or perhaps even a few, very rich samples which will directly indicate the location of some mineralization. On the other hand he may attempt to interpret every sample taken, and thereby to obtain a general pattern of the metal distribution in the area he is investigating. We do not wish too much to deprecate the first system, which perhaps accords best with the prospector's traditional gambling spirit.

Unfortunately, this first method of attack has little chance of success in exploration unless an inordinately large number of samples are taken, and the cost of doing this may be prohibitive. Furthermore, we have not yet perfected any simple field method whereby results can be obtained in a few minutes on the spot: water testing has a great advantage in this respect. Independent of this technical difficulty we have found that it is possible to get disappointing results from a single sample taken almost on top of a lode. In short we do not favor looking for mineralization by looking for samples with very high metal contents. The odds would seem too much against success. It would be like panning at random without taking the general geological background into consideration in an unknown area in the hope of finding a buried vein.

The second system which may be thought of as one in which a search is made for anomalous areas is undoubtedly slower and less spectacular, but we believe it capable of finding mineralization under unfavorable circumstances. Furthermore the biogeochemical data obtained by mapping anomalies can sometimes be of assistance in tracing geological formations in heavily drift-covered areas as well as drawing attention to any indications of mineralization.

If 50 or more samples of one species have been collected in an area it is possible to treat the analytical results independently of any previous data. This may best be done by plotting the results to a suitable scale on squared paper, giving what is termed a frequency diagram or histogram. By this diagram it is possible visually to estimate the normal copper, zinc, or copper: zinc ratio of the suite in question. In general, percentage variations from the normal are the significant items. Again speaking in general terms we have found that variations of more than 50 per cent and less than 100 per cent above normal may safely be termed "possibly anomalous" in the case of copper, and more than 100 per cent above normal "probably anomalous." In dealing with zinc somewhat smaller percentage variations appear significant: variations of more than 30 per cent and less than 50 per cent above normal are usually taken by us as being "possibly anomalous," and those of more than 50 per cent above normal as "probably anomalous."

To illustrate, we might cite results obtained in prospecting in a portion of southern British

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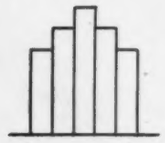
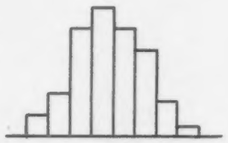
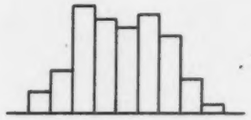


1
Artificial Culture

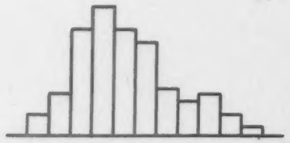


2
Homogeneous subsoil

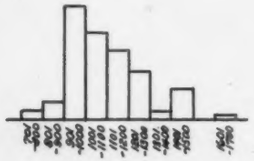


3
Subsoil involving two rock types

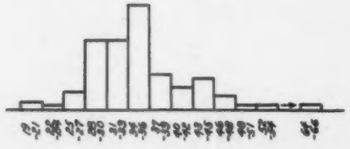
4
Subsoil with ore



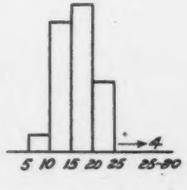
5
Sum of Diagrams 2 and 4
(compare with Diagrams 7,8,9 and 11.)



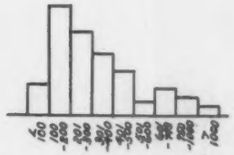
8
Zinc in Ash



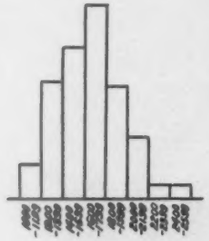
9
Zinc in dry plant



10
Iron in dry plant



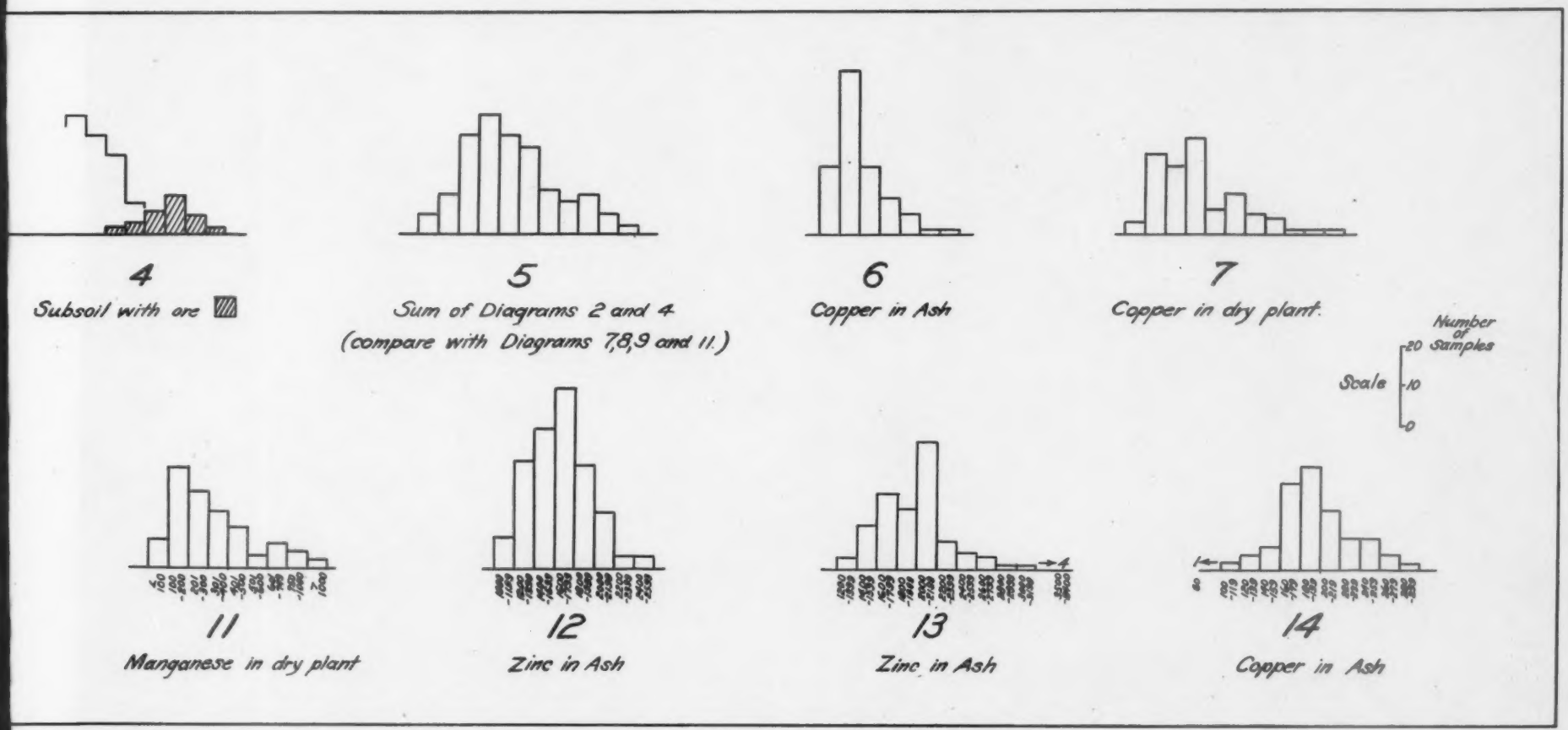
11
Manganese in dry plant



12
Zinc in Ash

TYPICAL HISTOGRAMS

Abscissae show metal content at various scales. All results in p.p.m. dry plant or ash as indicated. Ordinates indicate number of samples.
Diagrams Nos. 1 - 5 are typical histograms obtained from a large number of samples.
Nos. 6 - 14 are histograms resulting from actual field work from relatively small numbers of samples (about 100).



TYPICAL HISTOGRAMS

ious scales. All results in p.p.m. dry plant or ash as indicated. Ordinates indicate number of samples.
grams obtained from a large number of samples.
from actual field work from relatively small numbers of samples (about 100).

Columbia. We found that using twigs of one full season's growth 6 p.p.m. of copper and 42 p.p.m. of zinc could be considered a normal content of dry-plant material of this particular species. In this instance a copper content greater than 9 p.p.m., or zinc greater than 56 p.p.m., was considered as possibly anomalous, and 12 or more p.p.m. of copper and 63 or more p.p.m. of zinc as probably anomalous. In using copper:zinc ratios we have found it necessary to eliminate any samples which carry either copper or zinc in amounts significantly below normal for the area being investigated.

In selecting scales to be used in compiling a frequency chart, different units will have to be chosen to suit the particular circumstances under consideration: the number of analyses available, the species of tree being considered, and the anomalous element being sought are all factors which determine the selection of a suitable scale.

In most natural-history problems variations from a normal can best be shown on a logarithmic scale. However, in this particular case the higher contents are much more interesting than the lower ones, and consequently an ordinary scale may draw attention to anomalous specimens more strikingly than a logarithmic one, even though the latter would be technically more correct.

There will always be something arbitrary in deciding what is normal and what is not in any given area. Nevertheless during several years of investigations on trace metals we have noticed that for a given organ of determined age of any one species variations owing to different growing conditions on the same subsoil are usually of the same order of magnitude as variations due to different subsoils, always provided that there was no metal present as ore or a a notable addition to the country rock. Some limestones are abnormally high in copper.

In diagrams from areas of little or no mineralization most data will appear in a chart in a few brackets forming a compact pattern which we now consider a "normal" pattern (Pl. 1, Diagram 2). An ideal frequency diagram would be obtained from a lot of equally healthy plants growing on homogeneous soil without competition of any sort (Pl. 1, Diagram 1).

Actually in most areas many species are competing for existence, and geological and physiographical variations are inevitable. Thus in the absence of specific mineralization most diagrams look like Diagram 2. In some areas two widely differing geological formations will result in a "two-bumped" diagram such as Diagram 3.

In a mineralized area, such as a porphyry copper, occurring as a part of a much larger area, a small diagram, indicated on Diagram 4, will be superimposed on Diagram 2, giving a diagram such as Diagram 5.

Obviously there will be overlapping on some diagrams: the lowest copper content of organs from a mineralized area will overlap with the highest copper contents of some "normal" areas. This is unavoidable, but the greater the number of samples taken the less troublesome is the problem of overlapping. Equally obvious is the conclusion that no deductions should be drawn, except in conjunction with all available geological and physiographical data.

We have found it advisable when moving into new country to take, where convenient, samples of several species from the same place. Not all the samples are likely to be high by some physiological freak.

Diagrams 6–14 illustrate examples from our own experience. The weak copper anomaly indicated by Diagrams 6 and 7 has now been related to copper mineralization. The well-marked anomaly indicated on Diagrams 8 and 9 has been correlated with significant zinc mineralization.

Diagrams 12–14 come from an area now known to contain zinc with some copper, but with the copper being of no commercial importance, and indeed being only of mineralogical and biogeochemical significance.

We submit that, although Diagram 12 might well be said to have missed the zinc, now known to be present, the four samples beyond the normal right-hand scale of Diagram 13 could not fail to point to this zinc-anomalous area.

Having decided that some samples are anomalous there remains to decide on the best method of plotting the results. Ordinarily a map showing such geology and topography as is practical is prepared. Then a set of contour lines is superimposed indicating either the absolute amount of metal or the variation from the normal of the metal content of the plants within the area under consideration. White (1950) has illustrated this technique. As this

varies in no significant manner from geophysical practices it will not be discussed further here.

at all but one of the places indicated as anomalous. The commercial significance of this mineralization remains to be determined.

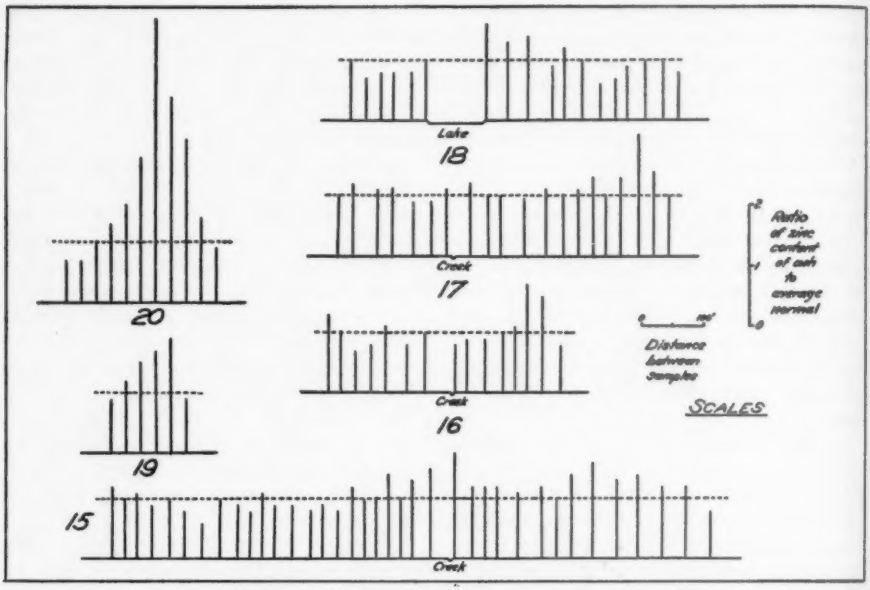


FIGURE 1.—TYPICAL BIOGEOCHEMICAL PROFILES

Each vertical line represents one sample. The length of the line is proportional to the ratio of the zinc contents to the normal for the species. The horizontal dotted line indicates this normal. The slope of the ground is not indicated because no survey was available when we made these studies.

Diagrams 15–20 (Fig. 1), inclusive, indicate how results obtained from a suite of samples taken across a valley of varying width may be plotted in the form of a profile to indicate where mineralization may occur. In these diagrams each sample is represented by a vertical line, the height of which expresses the ratio of the metal content to the normal metal content of the species, considering similar organs of the same age. The intervals between the vertical lines represent to scale the distance between the trees. The horizontal dotted line represents the normal metal content and is superimposed on the diagram in order to indicate more clearly the variations from the normal.

In all these diagrams significant variations can readily be seen, even though six species of trees were involved in this survey, and each species had its own normal zinc content. At the time of writing, mineralization had been found

COMMON ERRORS

We have discussed errors connected with collecting and now indicate some of the other pitfalls into which we have fallen.

(1) *Collecting samples from trees growing where there is too much dilution.* This seems a very obvious mistake, but it is a very natural mistake and one apt to be made by beginners.

Willow and alders frequently grow along river banks and lake shores. These rivers and lakes may contain exceptionally pure water, and we have found that these species, particularly where sampled too close to large bodies of water, may fail to indicate anomalies, whereas samples taken near by from less thirsty species may show anomalies. The same may apply to some species of spruce which are tolerant of extremely damp conditions.

It is desirable, therefore, where possible to

select samples removed from too ready access to large bodies of pure water.

Perhaps we can illustrate this point best by giving an example encountered in actual prospecting in 1949. A narrow zinc vein crossed a creek. A short distance below the outcrop the zinc content of the water in the creek was some 40 parts per thousand million. Nearly half a mile lower down the creek the water content was determined as 2 parts per thousand million, but this was sufficient to make the trees near the creek weakly anomalous. Just down-stream another creek entered, and further dilution took place. The zinc content of the water fell below 1 part per thousand million, and no anomaly could be detected in a carefully selected suite of samples.

(2) *Collecting samples from mine dumps and vein outcrops in order to discover what anomalies may be expected in an area.* It has been our experience that samples collected from the vicinity of mine dumps and conspicuous outcrops containing copper and zinc are most erratic in their content of these metals. In our early experiments we hopefully looked for spectacular results from samples taken in such auspicious localities. We were rudely surprised when we more often than not obtained "normal" results.

We are by no means certain that we have the answer to this puzzle. However, it may lie in the fact that trees obtain their metal content by means of base exchange, and this involves the presence of suitable particles of clay or claylike minerals.

(3) *Neglecting to take pH variations into account when these variations are significant.* We have no usable statistical information on this point, but we have collected some data on variations on the iron:manganese ratio of some species under varying pH conditions. From these and preliminary copper and zinc data collected at the same time we are convinced that the uptake and hence both the relative and absolute amounts of copper and zinc in plants are affected materially by the pH of the soil at the time of growth.

(4) *Neglecting to take into account the fact that there are biogeochemical provinces in much the same way that there are metallogenetic provinces.* We have studied only a few species in sufficient detail to offer supporting evidence of this statement. However, the general premise seems so reasonable that probably no further elaboration is necessary. In general it seems safe to assume that in any one geographic area the absolute and possibly the relative amounts of copper and/or zinc may vary markedly from those found in another. In staring work in a new area it is therefore necessary to determine as soon as possible what are to be considered normal contents. The safest way to do this is to collect suites from sterile outcrops. Normal contents usually appear from statistical curves which have been described above.

Conclusions

Although detailed work may enable one to obtain unusually high copper and zinc contents in trees and lesser plants, it seems clear that, in exploration work, biogeochemistry will prove its worth in the search for buried ore bodies through its ability to detect relatively unspectacular but nonetheless important anomalies.

We have concluded that for field work a stem of one season's growth is the most practical organ to use, except in a few special cases when leaves and stems cannot be separated easily.

Attempts to get results by using biogeochemistry without considering the relevant geology, climate, and physiography may result in much misdirected effort. Only rarely is it wise to use biogeochemistry alone. It is another tool which, when used under appropriate conditions, may play a useful part not only in the search for buried ore bodies but also in deciphering the distribution of some geological formations covered with overburden.

It is hoped that the many tables and diagrams given in this paper will aid those who attempt to apply biogeochemistry to their various problems.

References and Bibliography

Delavault, R. E., and Irish, R. I. (1949) *Emploi de la dithizone en solution ammoniacale*, Comptes rendus des séances de l'Académie des Sciences, Tome 229, p. 1079.

Hawkes, H. E. (1949) *Geochemical prospecting for ores: A progress report*, Econ. Geol., vol. 44, p. 706–712.

—— (1950) *Geochemical prospecting for ores*, Chapter 30 in Trask, P. D.: *Applied sedimentation*, John Wiley and Sons, Inc., p. 537–555.

Huff, L. C. (1948) *A sensitive field test for heavy metals in water*, Econ. Geol., vol. 43, p. 675–684.

Lakin, H. W.; Stevens, R. E.; and Almond, Hy (1949) *Field method for the determination of zinc in soils*, Econ. Geol., vol. 44, p. 296–306.

Leyton, L. (1948) *Mineral nutrient relationships of forest trees*, Forestry Abstracts, vol. 9, p. 399–408.

Reichen, L. E., and Lakin, H. W. (1949) *Field method for the determination of zinc in plants*, U. S. Geol. Survey, Circ. 41, 4 pages.

Robinson, W. O.; Lakin H. W.; and Reichen, L. A. (1947) *The zinc contents of plants of the Friedensville zinc slime ponds in relation to biogeochemical prospecting*, Econ. Geol., vol. 42, p. 572–582.

Sokoloff, V. P. (1948) *Geochemical prospecting for ore*, Mines Mag., vol. 38, p. 21–24.

Sylvestre, (Frère), C. S. C. (1942) *De la distribution du cuivre dans les principaux arbres du Québec*, Ecole des Hautes Etudes Commerciales de Montréal, Contrib. n°.18.

Warren, H. V., and Delavault, R. E. (1948) *Biogeochemical investigations in British Columbia*, Geophysics, vol. 13, p. 609–624.

Warren, H. V., and Delavault, R. E. (1949) *Further studies in biogeochemistry*, Geol. Soc. Am., Bull., vol. 60, p. 531–560.

—— —— —— (1950) *Gold and silver content of some trees and horsetails in British Columbia*, Geol. Soc. Am., Bull., vol. 61, p. 123–128.

—— — Howatson, C. H. (1947) *Biogeochemical prospecting for copper and zinc*, Geol. Soc. Am., Bull., vol 58, p. 803–820.

——; Delavault, R. E.; and Irish, R. I. (1949) *Biogeochemical researches on copper in British Columbia*, Roy. Soc. Canada, Tr., vol. XLIII, p. 119–137.

White, W. H. (1950) *Plant anomalies related to some British Columbia ore deposits*, Canad. Inst. Mining Metall., Bull., p. 368–381.

University of British Columbia, Vancouver, B. C.

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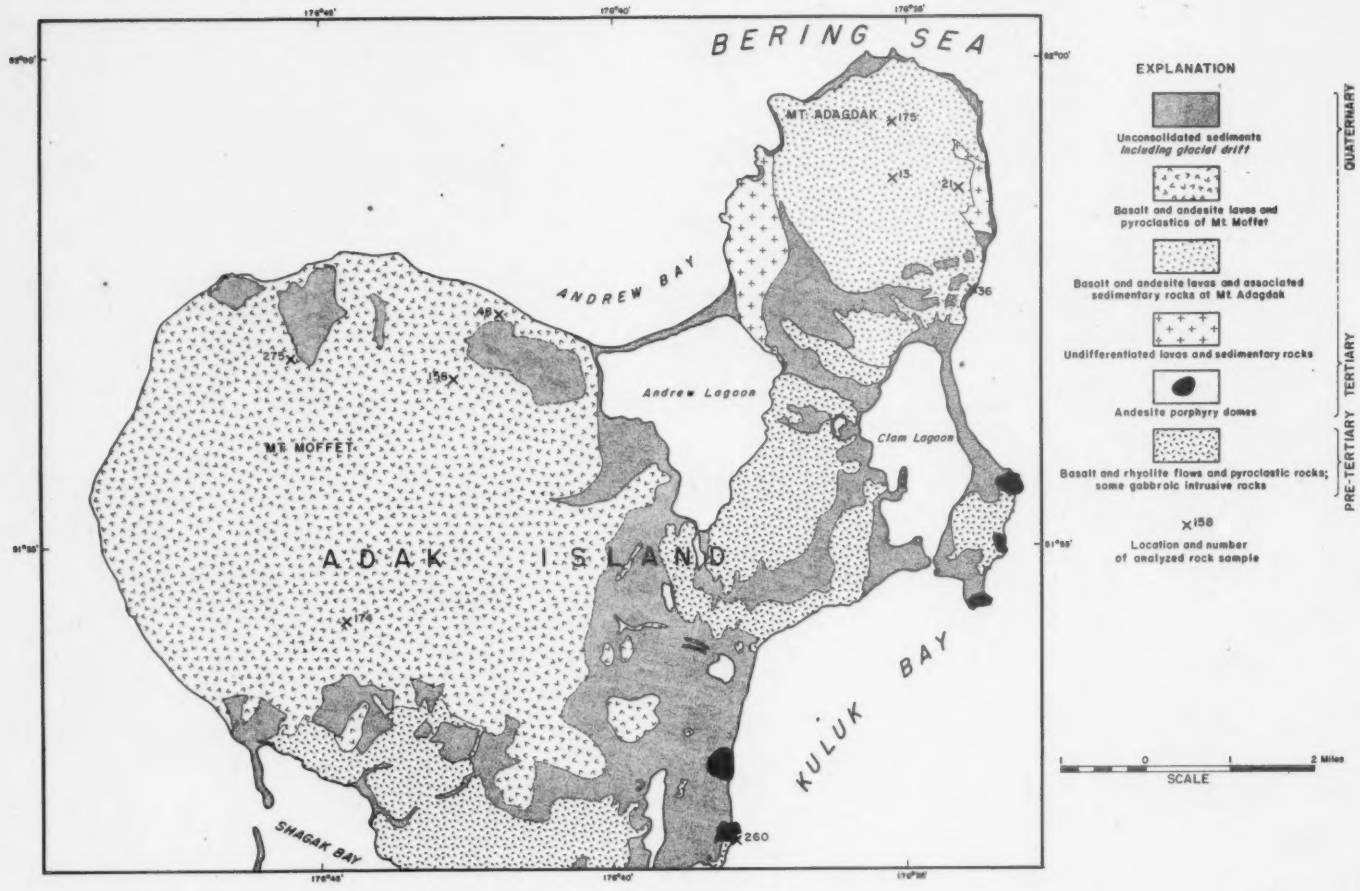

SIMPLIFIED GEOLOGIC MAP OF NORTHERN ADAK ISLAND, ALASKA, SHOWING LOCATIONS OF ANALYZED SPECIMENS

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MAGMATIC DIFFERENTIATION IN TERTIARY AND QUATERNARY VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS, ALEUTIAN ISLANDS, ALASKA

BY ROBERT R. COATS

ABSTRACT

Samples of 17 volcanic rocks of Tertiary and Quaternary age from Adak and Kanaga islands have been chemically analyzed and studied microscopically. Spectrograms have been made of 10 of them. The rocks from Adak represent one center of possibly older Tertiary age and two centers of younger Tertiary or Quaternary age. The rocks from Kanaga Island represent both a shield volcano of possibly Tertiary age, partly destroyed by the formation of a caldera, and a young cone of Quaternary age that has grown within the caldera.

All the rocks are basalt or andesite. Modally, all are characterized by relatively large crystals of plagioclase more calcic than andesine, and by one or more of the following ferromagnesian minerals: olivine, hypersthene, augite, and hornblende. Apatite and iron ores are common, and late silica minerals and orthoclase occur interstitially in the groundmasses of some rocks.

As analyses of no more than four samples are available for each center, the small differences between sets of analyses representing different centers are of doubtful significance. Consequently, the analyses representing all the centers have been plotted on each of the several diagrams used.

The several types of variation diagrams show that the province is a calc-alkaline one. The alkali-lime index is in the neighborhood of 63. This very high value is comparable with that for Katmai and is only slightly less than the maximum for the Japanese volcanic rock series.

The quantities of minor constituents present are not exceptional for the rock types analyzed; the rocks from Adak are apparently more strontium-rich than those from Kanaga.

The chemical analyses of the more basic rock types, as compared with the average analysis of plateau basalt, suggest that the Aleutian parental magma could have been derived from a plateau basalt magma by the addition of plagioclase and the subtraction of pyroxene, iron ore, and some quartz. The distribution of the minor elements can be explained more easily by postulating that, at least on Kanaga Island, some sediments have been assimilated.

The derivation of the analyzed rocks from the Aleutian parental magma is most easily explained by the hypothesis that the plagioclase remained in suspension while the ferromagnesian minerals were settling out.

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Introduction

The Aleutian volcanic arc extends 1580 miles from Mt. Spurr, on the Alaskan mainland, westward to Buldir Island. It is one of the least-studied great marginal arcs of the Pacific Basin. The eastern end of the arc follows closely the tectonic lines of the Alaska Peninsula and of the southwestward prolongations of the Alaska Range; the western end crowns a narrow ridge, rising abruptly from the 4000-fathom depth of the Aleutian Trench on the south, and on the north from the 2100-fathom depths of the remarkable flat-floored basin that forms the western portion of the Bering Sea. It was, no doubt, the orographic resemblance of this western portion to the intra-Pacific chains of volcanic islands that led Fenner (1926a, p. 124–127) to suggest that the differentiation of the western part of the chain, at least, ought to be similar to that of the intra-Pacific volcanoes. This hypothesis is not substantiated by recent work.

Adak and Kanaga islands, while lying well west of the geometric midpoint of the Aleutian arc, are among the most southerly of all the islands (Fig. 1). Together with Great Sitkin, they are the sites of Quaternary volcanism nearest to the important military base of Adak, and thus a logical area in which to begin the study of the volcanoes of the western part of the Aleutian arc. The preliminary results of this reconnaissance study, begun in 1946, appeared in 1947 as parts 4, 5, and 6 of Report No. 2, Alaskan Volcano Investigations of the U. S. Geological Survey. Petrographic descriptions of the more important rock types, given in that publication, make it evident that the rocks of this part of the Aleutian chain are principally basalts and andesites and do not differ greatly from those of other circum-Pacific volcanic arcs, or from those of other parts of the Aleutian chain.

The writer has benefited greatly from discussion with and criticism from several of his colleagues of the Geological Survey, particularly G. D. Robinson, H. A. Powers, F. M. Byers, Jr., G. A. Macdonald, J. B. Mertie, Jr., K. J. Murata, and W. G. Schlecht; but he must assume sole responsibility for the conclusions presented.

Nature of Volcanic Activity Represented by the Analyzed Rocks

On Adak Island (Pl. 1) the earliest known episode of the Cenozoic volcanic history is now

FIGURE 1.—INDEX MAP OF ALASKA, SHOWING THE LOCATION OF ADAK AND KANAGA ISLANDS

represented only by a small number of light-colored hornblende-biotite andesite domes[1], with conspicuous plagioclase crystals. A single analysis of a sample from one dome is available. The later episodes of that history pertain to three separate centers, one of which has been largely removed by marine erosion. The two major centers, Mt. Moffett and Mt. Adagdak, are represented by analyses. Mt. Adagdak is a basaltic shield volcano, crowned by a compound composite cone; the crater of the latest center is occupied by two volcanic domes.

Mt. Moffett consists of a main composite cone and a parasitic cone on the northeast flank, with extrusive domes on the flanks of both. A late tuff-breccia cone on the crater of Mt. Moffett was finally filled by an andesitic plug.

On Kanaga Island (Pl. 2), a large basaltic shield volcano, which has been called Mt. Kanaton, was eviscerated, probably in the Pleistocene, with the formation of a caldera about 4 km in diameter and the eruption of a considerable thickness of andesitic pumice. The caldera has subsequently been partly filled by the growth of a composite cone of andesite and basalt, Kanaga Volcano, which has been in eruption in recent years. A somma lake has been formed between the young cone and the southwest corner of the caldera wall.

Petrographic Character of the Rocks

Summary of Petrography

The rocks, considered without regard to provenance, may be divided into three main groups, on the basis of either silica percentage or mineral composition; the two bases give fairly consistent divisions. These groups are: olivine basalts; olivine basalts with hypersthene, hornblende, or both; and andesites with hypersthene, hornblende, or both.

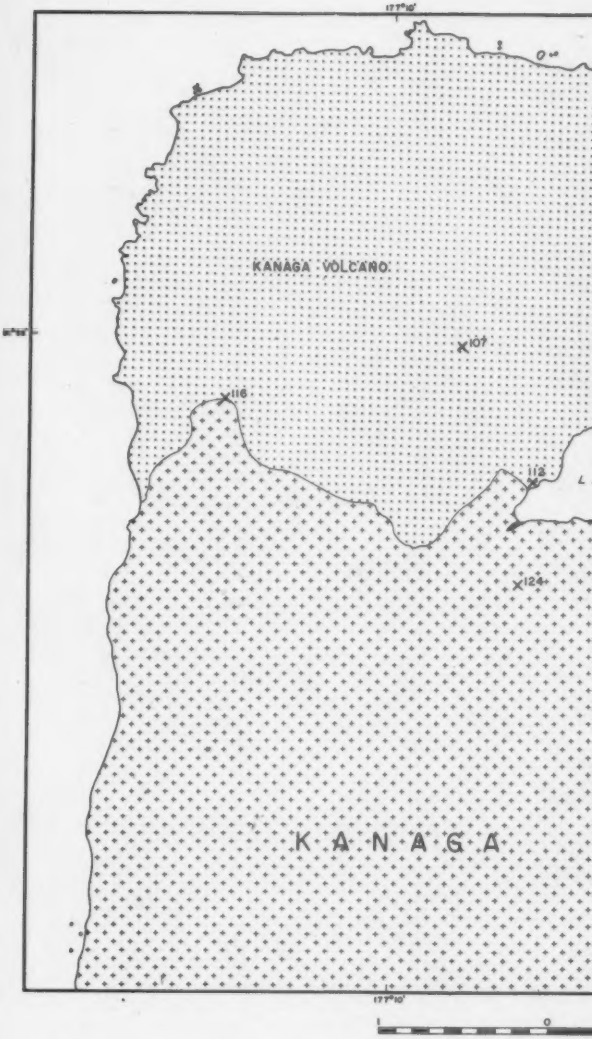
All the rocks are characterized by relatively coarse plagioclase. Many contain coarse clinopyroxene, smaller crystals of hypersthene, olivine, and hornblende, with accessory ilmenite, magnetite, and apatite. The interstitial material is glass, or orthoclase, or even sodic plagioclase. The texture is not, strictly speaking, porphyritic, as crystals of all sizes are present. Only one of the analyzed rocks (46AC260), a hornblende-biotite andesite from a dome of Tertiary age on Adak, contains biotite. Tridymite and cristobalite are common as late cavity fillings and vesicle linings, but they make up only a small part of the total bulk. Some evidence suggests that, with increasing silica content, the hypersthene becomes more iron-rich. Hornblende appears to proxy for hypersthene. Crystals of hypersthene commonly are surrounded by jackets of clinopyroxene. Late clinopyroxene may have a slight tendency to become more pigeonitic in the more silicic rocks, but the evidence depends on the determination of the optic axial angle of the ground mass augite, which is commonly in grains too minute for this determination. The plagioclase is slightly more albitic in the more silicic rocks, but the ranges overlap; plagioclase crystals commonly show long sequences of oscillatory zoning, different from one crystal to the next.

The olivine basalts have silica contents up to 52 per cent. The plagioclase ranges in composition from An_{98} to An_{31}. The few determinations of the olivine composition suggest a composition of about Fo_{71}. The clinopyroxene is probably aluminous, judging from the dispersion, but atomic ratios shown in the descriptions are derived from optical properties determined on more or less aluminous pyroxenes (Hess, 1949, p. 633).

Olivine basalt, with hornblende or hypersthene or both, falls in the range from 52 to 56 per cent of silica. The plagioclase, which is strongly zoned, ranges in composition in the analyzed specimens from An_{92} to An_{62}. The clinopyroxene is similar to that of the olivine basalts. The hypersthene, judging from the axial angle, has a composition of approximately En_{85}. The hornblende is typically basaltic in habit. The groundmass is generally glassy.

The andesites are characterized by the presence of hornblende, hypersthene, or both, and contain more than 56 per cent SiO_2. The plagioclase ranges in composition from An_{94} to An_{46};

[1] "Domes" is used in this paper in the sense used by Williams (1932, p. 54). It is nearly equivalent to *Quellkuppe*.



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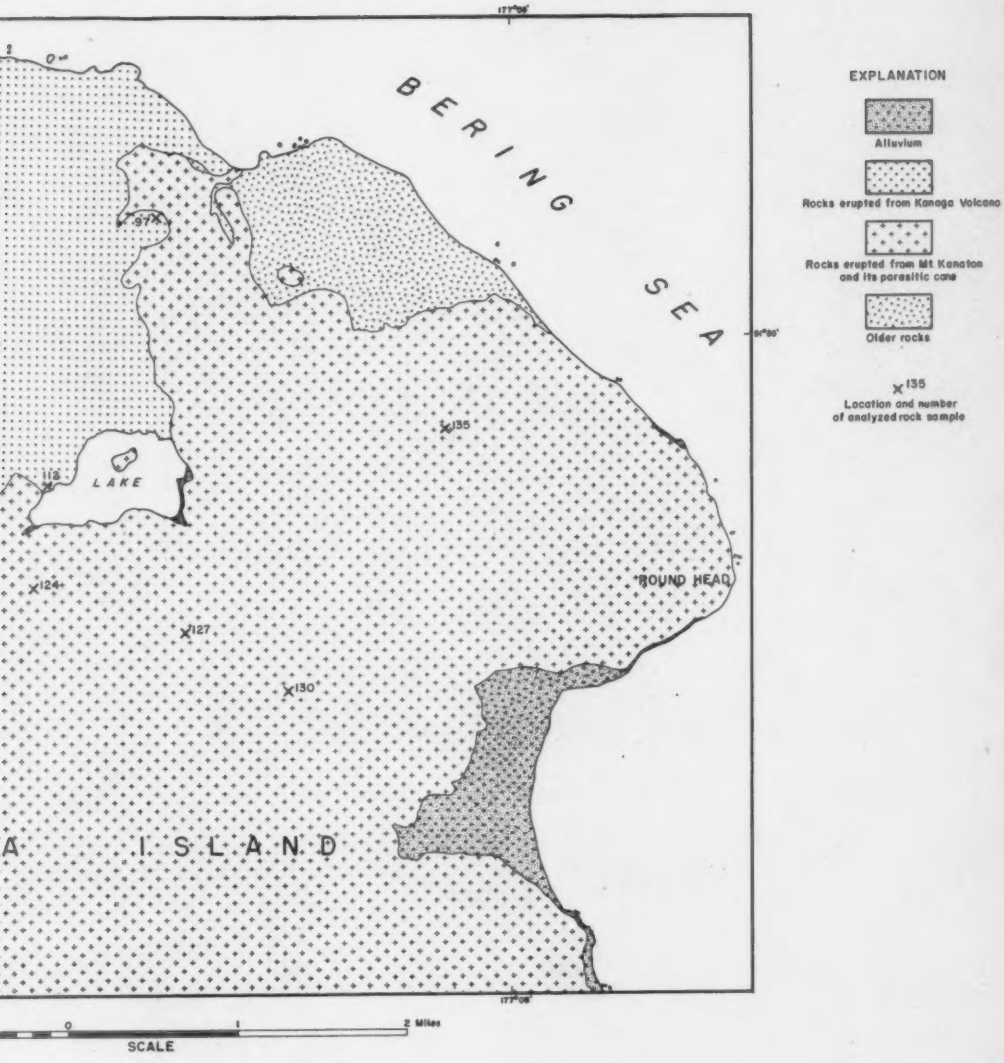

GEOLOGIC MAP OF NORTHERN KANAGA ISLAND, ALASKA, SHOWING LOCATIONS OF ANALYZED SPECIMENS

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the crystals are as much as 3 mm long. Clinopyroxene crystals reach a maximum length of 0.5 mm, and locally are pigeonitic. The hornblende is basaltic and generally strongly resorbed, to form magnetite and augite.

Petrographic Descriptions of the Analyzed Rocks

The petrographic descriptions of most of the analyzed rocks are based on the study of a single thin section of the sample analyzed, supplemented by study of crushed fragments of the principal minerals in immersion oils. Usually only enough optical properties of the minerals were determined to permit determination of the composition of the minerals. Most use was made of the charts compiled by Kennedy (1947) and of the work of Hess (1941; 1949). In the determination of plagioclase, I usually relied on what may be termed the median index: the index of refraction of the immersion medium in which half of the randomly oriented grains appear to have a higher index and half a lower index than the medium. If perfect randomness of orientation were achieved, then for a mineral like plagioclase, in which nY is nearly the mean of nZ and nX, the median index would be about equal to nY. Because of the tendency of plagioclase grains to lie on one of the two principal cleavage faces, randomness is not achieved, and I estimate that the actual median index is probably less than nY by about a third the difference between nY and nX. It is realized that compositions determined by this method are not very accurate, particularly in any grain not at extinction, where the apparent motion of the Becke line depends upon the relative intensity of the two transmitted rays that travel with different velocities in the mineral. Further bias may be introduced by differences in the perfection of different cleavages from one specimen to another, and by the fact that nY is not precisely the mean of nZ and nX for most compositions. In view, however, of the dependence of the optic orientation upon the thermal history of the feldspars (Kohler, 1949) and the pronounced zoning shown by most of the larger grains of plagioclase, it seems probable that the average composition of the plagioclase can be better estimated by this method than by any method involving determinations of extinction angles in thin sections.

The color names and designations of the Munsell system, as modified in the Rock-Color Chart distributed in 1948 by the National Research Council, are used. Percentages, where given, are volume percentages, based on visual estimates from the thin section, and refer to the volume, or area, of the whole section.

The petrographic descriptions are identified by the field numbers of the samples, followed by the stratigraphic name used in the original publication (differing in some cases from the petrographic name), by the location from which the sample was taken, and by the petrographic name.

ADAK ISLAND

ANDESITE PORPHYRY DOME OF TERTIARY AGE:

46AC260. Zeto point basalt porphyry, from the Sand Hill Quarry, about half a mile north of the breakwater at the entrance to Sweeper Cove. Hornblende andesite porphyry. A medium light-gray (N7) porphyritic rock, about one-fourth phenocrysts. Phenocrysts are predominantly plagioclase, ranging in size[2] from 5 to 0.1 mm. The median composition of the plagioclase is about An_{55}. Many of the phenocrysts show reverse zoning to a composition of about An_{70}, succeeded by normal zoning to about An_{50}. Hornblende is the commonest of the colored constituents; the prisms show outer rims of augite, which are due to reaction with the magma. The single large flake of biotite has a reaction rim of magnetite and is embedded in green hornblende. One rounded grain of quartz has the appearance of a xenocryst. The groundmass consists of plagioclase, averaging about An_{40}, quartz, and orthoclase. Some calcite is in part interstitial to clear, unaltered plagioclase crystals of the groundmass, but has developed a reaction border of epidote against augite.

MT. ADAGDAK (In approximate order of age, oldest first):

46AC36. From interbedded basaltic lava flows and tuffaceous sandstones, at a point 4550 feet S. 5° W. of triangulation station "Clam" and about 4000 feet northeast from the northeast corner of Clam

[2] "Size" as used in petrographic description refers generally to maximum linear intercept in thin section.

Lagoon. A dense porphyritic, olivine basalt, light brownish-gray (5YR 6/1). About 85 per cent phenocrysts, chiefly plagioclase, salite, and olivine. Plagioclase clear, ranging in size from 2 to 0.2 mm, in composition from An_{88} to An_{54}, with a median of about An_{67}. Extreme outer zones reach An_{10}. Salite crystals are greenish-black (5G 3/1) in hand specimen, reaching a size of 4mm. N_X is 1.701 and n_Z 1.728, corresponding to salite with atomic proportions of $Fe_{25}Ca_{40}Mg_{35}$. Olivine, which is sparse, reaches a size of about 1mm, in honey-yellow (10YR 6/4) crystals, with nY about 1.714, corresponding to Fa_{30}.

46AC13. Part of older composite cone, from summit of ridge, 3400 feet S. 21° E. of summit of Mt. Adagdak. Blotched and streaky hornblende andesite lava, with some strands light brownish-gray (5YR 7/1) and others medium light gray (N6). Texture seriate, with conspicuous crystals of plagioclase and hornblende up to 2 mm, sparser and smaller crystals of augite and olivine up to 0.2 mm. The median composition of the coarser plagioclase crystals is about An_{58}. The hornblende is typical "basaltic" hornblende, with small exinction angle, and is pleochroic from red-brown to yellow. The maximum index is about 1.743 and the minimum index about 1.678. The salite has nX1.68, suggesting about $Ca_{40}Mg_{40}Fe_{20}$. Accessories include apatite, as pseudodichroic stubby prisms, and magnetite. Much hematitic dust is present in the groundmass, which consists principally of anhedral oligoclase (?), tridymite (?), magnetite, and needles of augite.

46AC21. From dome about 6350 feet S. 51° E. of summit of Mt. Adagdak. Basalt. A light brownish-gray (5YR 5/1) rock, with seriate texture and numerous flattish, irregular vesicles. The larger plagioclase crystals, ranging in size from 4 to 0.1 mm, have a median composition of about An_{60}. The dark-green salite has a maximum size of about 3 mm with a maximum index of about 1.721 and a minimum index of 1.690, suggesting a composition near $Ca_{40}Mg_{30}Fe_{30}$. Small amounts of "basaltic" hornblende, pleochroic in red-brown and yellow colors and with wide resorption borders of magnetite, are also present. The groundmass consists of plagioclase laths, rods of augite, granules of magnetite or ilmenite, and interstitial glass in small amount. Small prisms of apatite and irregular grains of magnetite or ilmenite are the principal accessory minerals.

46AC175. From summit dome of Mt. Adagdak, at a point 800 feet N. 78° E. of summit. Hornblende andesite. A compact, light pinkish-gray (5R 7/1) rock, with conspicuous crystals of white plagioclase and black hornblende, and a seriate texture. The median composition of the larger plagioclase crystals is about An_{57}; the maximum size is about 2 mm. The hornblende forms brilliant narrow prisms, as much as 1.5 mm long, greenish-brown in thin section, and showing marginal resorption to clinopyroxene. The larger salite crystals have nZ 1.715 ± 0.005, or about $Ca_{50}Mg_{35}Fe_{15}$. The groundmass, with a mean grain size of about 0.002 mm, is apparently an intergrowth of quartz and orthoclase, with prisms up to 0.008 mm long of pyroxene and grains of iron ore about 0.003 mm across. Cristobalite lines vesicles and fills obscure cracks and replaces some of the groundmass.

MT. MOFFET:

46AC48. Part of composite cone of Mt. Moffet, from flow exposed on sea cliff, about 5800 feet N. 50° E. of summit of parasitic cone of Mt. Moffet and about 7400 feet west-northwest of northwest corner of Andrew Lagoon. Compact, holocrystalline, pale-red (5R 5/1) olivine basalt with seriate texture. About 60 per cent of crystals of plagioclase are from 2 to 0.2 mm in diameter and range in composition from An_{84} to An_{31}, with a median of about An_{72}. The augite crystals, which reach a maximum size of 3 mm and make up about 5% of the rock, are olive-black (5Y 2/1) in hand specimen. The maximum index is about 1.72 and the intermediate index about 1.70, suggesting a composition near $Ca_{50}Mg_{30}Fe_{20}$. The olivine is a dark yellowish-orange in hand specimen (10YR6/6) and the largest grains are about 0.5 mm across. The indices determined are nX 1.688 ± 0.002 and nZ 1.726 ± 0.003, indicating a composition of about Fa_{28}. The principal accessories are magnetite and ilmenite in grains from 0.5 to 0.2 mm; the groundmass consists of blocky plagioclase crystals, augite granules, magnetite, and interstitial orthoclase.

46AC158. Part of parasitic cone of Mt. Moffet, 2400 feet S. 81° E. of its summit. Medium light-gray (N6) olivine basalt flow. Vesicular, with seriate intersertal texture. Plagioclase crystals reach a maximum size of 1 mm and have a median composition of about An_{72}. The outer rims and smaller crystals are oligoclase. The salite, which attains dimensions of 3 mm, and makes up about 6% of the rock has nZ 1.722 ± 0.003, nY 1.698 ± 0.003, and nX 1.688 ±0.003 suggesting a composition of $Ca_{45}Mg_{32}Fe_{18}$. Olivine crystals attain a maximum size of 1 mm, are clove-brown, and have nX 1.694 and nZ 1.743, suggesting a composition of Fa_{30-34}. Magnetite in rounded grains, as much as 1 mm across, is the principal accessory mineral. A few cumulophyric clots of magnetite, olivine,and clinopyroxene are present. A small amount of cloudy glass remains. Irregular vesicles are lined with tridymite.

46AC174. From one of the late domes of Mt. Moffet (Hill 1981) about 11,000 feet S. 5° E. of the summit of Mt. Moffet. Medium-gray (N5) hypersthene basalt, with a seriate, intergranular texture. The most conspicuous crystals are of plagioclase, up to 3 mm in size, with a median composition ranging from An_{44} to An_{49} in different specimens. The sparse salite as much as 0.5 mm in size, has nZ 1.716 and nX 1.688. This suggests a composition of about $Ca_{50}Mg_{34}Fe_{16}$. The sparse hypersthene, which is present in grains up to 0.5 mm in size, has a maximum index of 1.70, suggesting a composition of about $En_{72}Fs_{28}$. Olivine is very rare, and is characterized by a heavy reaction border and segregations of opaque material, apparently magnetite, along cleavage planes. Hornblende, which has a heavy resorption border of clinopyroxene, is very rare. Similar borders are also found on some grains of olivine and hypersthene. Magnetite and apatite are common accessories; the latter may be clear, where inclosed in hypersthene for example, or pseudodichroic, where exposed to reaction with the last part of the magma to crystallize. The groundmass consists of plagioclase laths, clinopyroxene granules, and interstitial orthoclase (?). Tridymite lines fractures and cavities, and is, in part, pseudomorphous after cristobalite.

46AC275. From composite cone of Mt. Moffet. Flow 5000 feet N. 23° W. of summit of Mt. Moffet. Medium light-gray (N5) olivine-hypersthene basalt, with seriate pilotaxitic texture and dense structure. Plagioclase crystals, as much as 3 mm in size, have a median composition of about An_{78} for the larger crystals and show strong zoning. The salite grains, which reach a maximum size of 1 mm, have nZ 1.73, nX 1.692, and 2V 60°, suggesting a composition of $Ca_{50}Mg_{35\text{-}20}Fe_{15\text{-}40}$. The crystals are visibly zoned, with the higher index material on the outside; the highest and lowest indices obviously do not represent the same material. The highest index measured for hypersthene was 1.699, suggesting a composition of $En_{71}Fs_{29}$. The olivine, which attains a maximum size of 0.5 mm, has nZ 1.699, corresponding to Fa_{15}. Magnetite in irregular grains up to 0.1 mm, and apatite, in pseudodichroic prisms, are the principal accessories. Orthoclase (?) was apparently the last mineral to crystallize.

Kanaga Island

Mt. Kanaton (relative ages not indicated by order):

46AC124. Lava flow, part of series forming Mt. Kanaton. About 10,950 feet S. 23° E. from the center of the crater of Kanaga Volcano. Hypersthene andesite. Light gray (N7) hypersthene andesite. Structure porphyritic, vesicular, with hyalopilitic groundmass. Megaphenocrysts (2%) from 1.5 to 3 mm are of plagioclase only; the remainder of the constituents are nearly all less than 0.75 mm. The plagioclase phenocrysts have a median index of about 1.557, suggesting a median composition of about An_{44}. Crystals are strongly zoned, many with zones of inclusions. Salite crystals, some as much as 1 mm long, are dark greenish-black in hand specimen and pale-greenish in thin section. The extinction angle of 41½° suggests a composition of $Ca_{50}Mg_{35}Fe_{15}$ (equivalent to $Di_{85}He_{15}$). The hypersthene prisms have nZ 1.710, suggesting a composition of $En_{66}Fs_{34}$. Olivine is present in rare grains, up to 2 mm; they are black in hand specimen and have an iridescent luster on fracture surfaces. Under the microscope the olivine appears to be permeated by chains of tiny crystals of an opaque black mineral. As fragments of the olivine are strongly attracted by a hand magnet, this mineral is presumed to be magnetite. The mean index of the olivine is 1.682, suggesting a composition of $Fo_{85}Fa_{15}$. The principal accessories are magnetite, which forms irregular grains from 0.05 to 0.25 mm in size, and apatite, which forms stout pseudodichroic prisms. The groundmass consists of plagioclase laths, augite rods, a few prisms of apatite, small grains of magnetite or ilmenite, and a little interstitial orthoclase. Tridymite, in crystals as much as 0.5 mm across, is a common vesicle lining.

46AC127. Lava flow, part of series forming Mt. Kanaton. About 5600 feet S. 20° E. from the summit (1145 feet) of the island in the somma lake. Medium dark-gray (N4) hypersthene-olivine basalt flow. Plagioclase phenocrysts, ranging in size from 0.1 to 4 mm, are conspicuously zoned. The median composition, judging from the index, is about An_{82}. The dark-green augite crystals, ranging in size from 0.1 to 3 mm, have nZ 1.718 corresponding to $Ca_{50}Mg_{32}Fe_{18}$. Hypersthene prisms have nZ 1.703, suggesting a composition of $En_{72}Fs_{28}$. Olivine, in grains as much as 1 mm across, has nZ 1.70, corresponding to a composition of $Fo_{85}Fa_{15}$. Small grains of magnetite or ilmenite are the principal accessory. The groundmass consists of plagioclase laths about 0.01 mm long and augite rods and granules up to 0.005 mm wide, in a brown glass, with an index of 1.505.

46AC135. Lava flow, part of series forming Mt. Kanaton. 10,100 feet N. 84½° E. from the summit of the island in the somma lake. Light-gray (N7) olivine basalt, compact, holocrystalline, porphyritic, with intergranular texture. The larger plagioclase crystals, ranging in width from 0.1 to 3 mm. have a median composition, judging from the refractive index, of about An_{82}. Salite phenocrysts ranging in size from 0.1 to 5 mm, have nZ 1.723, suggesting a

composition of $Ca_{50}Mg_{37}Fe_{13}$. The olivine crystals which range in size from 0.5 to 0.07 mm, have Nz 1.72, suggesting $Fo_{76}Fa_{24}$. Magnetite or ilmenite, in irregular grains, from 0.5 to 0.1 mm, is the principal accessory. The groundmass consists of plagioclase laths, with median composition from An_{57} to An_{45}, with interstitial augite and magnetite or ilmenite grains, and partial outer rims of orthoclase on the plagioclase laths.

46AC130. Andesite tuff, probably representing the caldera-forming eruption, from 9800 feet S. 36° E. of summit of island in the somma lake. From a layer of yellowish-gray (5Y8/1) pumice, 1 to 2 feet thick, composed of fragments of pumice up to ¼ inch across; during shipment, most of the coarser material was crushed, so that after shipment only about 5% of the material was coarser than 10 mesh. Of the coarser material, about half was made up of fragments of accidental and accessory rocks, the rest of essential and cognate material, largely pumice and cognate crystalline rocks.

Of the material finer than 10 mesh, about 3% of the total sample was thought to be accidental and accessory material, divided about as follows: 30% plagioclase, 30% rock and glass, 20% pyroxene (augite and hypersthene), 10% magnetite or ilmenite, and 10% basaltic hornblende.

Essential and cognate material makes up about 92% of the total; it includes the 81% of glass, the 1% of magnetite, the 1% of green hornblende, and the 9% of plagioclase. The chemical analysis was made on the material finer than 10 mesh; it is probable that the elimination from analyzed material of the accidental and accessory fragments did not change any of the analytical values by as much as 3%, for the reason that the composition of the accidental and accessory material could not have differed very greatly from that of the essential material.

The essential material of the eruption is a clear, pumiceous glass, with index ranging from 1.495 to 1.505, containing phenocrysts of plagioclase, green hornblende, magnetite, and apatite. The plagioclase is zoned, and has a mean composition of An_{52}. The hornblende is clear, with a slight development of magnetite along the cleavages of a few grains. The pleochroism formula is: Z = olive-green, Y = yellowish-green, X = greenish-yellow. The extinction angle on (010) is 14°. The nZ is 1.676, nX is 1.653. The magnetite or ilmenite is in equant grains, about 0.2 mm in maximum width. Apatite is in clear, stubby prisms, with sharp prismatic terminations. It may be noted that the index of the glass is rather lower than that to be expected from the diagrams of George (1924).

KANAGA VOLCANO (present cone, relative ages not indicated by order):

46AC107. Lava flow, 3650 feet S. 42½° E. from center of crater of Kanaga Volcano. Medium light-gray (N6) slightly vesicular hypocrystalline hypersthene andesite, with seriate texture. Larger plagioclase crystals, from 0.1 to 4 mm in size, range in composition from An_{77} to An_{45}; most crystals are conspicuously zoned. The larger salite crystals, which attain a size of as much as 1 mm, are dark-greenish and have nZ 1.724, suggesting a composition of $Ca_{40}Mg_{37}Fe_{23}$. The hypersthene, which is in euhedral prisms from 0.1 to 1 mm, has nZ 1.707, corresponding to a composition of $En_{68}Fs_{32}$. Magnetite, in irregular grains from 0.2 to 0.01 mm, and apatite, in stubby pseudodichroic prisms, are the principal accessory minerals. The groundmass consists of laths of oligoclase (median composition An_{28}) and needles of pyroxenes, in a mosaic of orthoclase (?) and a clear glass with an index of 1.495 ± 0.003.

46AC112. Lava flow, 8400 feet S. 33½° E. from the center of the crater of Kanaga Volcano. Medium light-gray (N6) hypersthene andesite, conspicuously porphyritic and irregularly vesicular. Phenocrysts include plagioclase, augite, hypersthene, and hornblende. Plagioclase is labradorite with a median composition of An_{53}, in crystals ranging in size from 0.1 to 2 mm, commonly zoned, with the sequence of zones differing from one crystal to another. Salite, in dark-green crystals ranging in size from 0.1 to 0.5 mm, has nZ 1.712, suggesting a composition of $Ca_{45}Mg_{42}Fe_{13}$. Hypersthene has nZ equal to 1.70, suggesting a composition of $En_{72}Fs_{28}$. Many of the hypersthene crystals have jackets of augite. The hornblende crystals are considerably resorbed, and are pleochroic from dark reddish-brown to yellow. The accessory minerals are magnetite or ilmenite, and pseudodichroic apatite prisms. The groundmass consists of plagioclase crystals and augite needles in pale-brown glass whose index ranges from 1.50 to 1.495.

46AC97. (1906 lava?) 8300 feet N. 80° E. from the center of the crater of Kanaga Volcano. Medium-gray (N5) vesicular hypersthene basalt, seriate in texture, with fluidal groundmass. The plagioclase crystals, some of which are as much as 4 mm in diameter, are generally zoned; in many the zones are marked by concentrations of inclusions of the groundmass materials. The median composition of the larger plagioclase crystals in about An_{60}. Salite, which forms about a fourth of the rock, has $Z \wedge c$ 43° to 44½°, 2V 60°, and nZ 1.720, suggesting a composition of about $Ca_{50}Mg_{30}Fe_{20}$. Hypersthene which forms about 5% of the rock, is in brown prisms, in part with augite jackets, has nZ

1.707 ± 0.002, corresponding to $En_{65}Fs_{35}$. Olivine, which is rare, has a negative 2V of 85°, corresponding to $Fo_{72}Fa_{28}$. The principal accessories are magnetite or ilmenite, which amounts to about 5% of the rock, and apatite in stubby, pseudodichroic prisms. The crystals are embedded in brown glass, with an average index of 1.505.

46AC116. (1906 lava?) 6400 feet S. 49½° W. from the center of the crater of Kanaga Volcano. Medium dark-gray (N4) hypersthene basalt, porphyritic, with vesicular structure. Placioclase phenocrysts range in size from 0.1 to 3 mm. The median composition is An_{48}, but one rounded grain of anorthite (average index 1.58) was seen and presumed to be a xenocryst. The salite crystals have nY 1.70, suggesting a composition about $Ca_{50}Mg_{30}Fe_{20}$. The hypersthene prisms, which range in size from 0.1 to 1 mm, have nZ 1.70 corresponding to $En_{73}Fs_{27}$. The optic axial angle of the olivine seen in thin section was the same as that in 46AC97, suggesting that here also its composition is about $Fo_{72}Fa_{28}$. Olivine is rare, and no olivine was found in the crushed fragments. The groundmass consists of plagioclase laths and augite rods in brown glass with an index of 1.50 ± 0.005. The accessory minerals are magnetite or ilmenite, from 1 to 0.1 mm, and apatite, in stubby prisms, 0.05 mm long, clear where included in hypersthene or salite but with a slightly pseudodichroic rim elsewhere.

Chemistry of the Rocks

Major Constituents

Analyses.[3]—Table 1 shows: (A) the chemical analyses of the 17 samples of volcanic rock from Adak and Kanaga Islands; (B) the results of spectrographic analyses for minor elements of 10 of these rocks; (C) the norms calculated by the use of von Philipsborn's Tabellen (1933); and (D) the Niggli values. The amounts of minor elements reported in part (B) are not considered in the calculation of the norms or of the Niggli values. Only very small changes in the calculated values would be produced by their use in the calculation. The analyses are given as reported by the analyst, although none of the values beyond the third, and in some cases the second, significant figure are regarded as having great significance.

Variation diagrams and the nature of the province.—Figure 2 is a plot of the weight percentages of the several oxides against the weight percentage of silica. In addition to the small symbols representing the rocks of the Aleutian Islands, similar but larger symbols representing the values of some pertinent averages are plotted on the same chart. These include the averages of two of the more silicic members of the porphyritic central type of Mull (Numbers II and V, H. H. Thomas and E. B. Bailey, 1924, p. 24 and also Daly's average plateau basalt and average diorite (Nos. 60 and 48, Daly 1933, p. 16 and 17).

The variation diagram indicates that the province is calcalkaline. The bulk of rocks of this part of the province and all the analyzed rocks from Adak and Kanaga are in the subsilicic and mediosilicic range; more highly silicic rocks have been found at Umnak (Byers, F. M. Jr., personal communication) and Katmai. The alkali-lime index (Peacock, 1931, p. 54) is about 63, which is a very high value. The index for the common Japanese volcanic rocks is 65.5; that for Katmai is 63.8 (Tsuboi, 1934, p. 22–71). In Peacock's classification, the province is calcic.

Geographic differences within the group of analyzed rocks are not evident from an inspection of Figure 2. The oldest analyzed rock from Adak contains less iron and magnesium than the younger rocks of corresponding silica content. The rocks from Kanaga Island appear to be consistently a little higher in potassium than those from Adak. The rocks of Mt. Kanaton are higher in magnesium and lower in calcium than other rocks of corresponding silica content from Kanaga Island.

[3] After the manuscript of this report was completed, silica and the alkalies were redetermined on five of the analyzed rocks in the laboratories of the U. S. Geological Survey: silica by Richard L. Hill, and alkalies by Mrs. S. M. Berthold, using the flame photometer. The following results have been used in correcting the norm and the Niggli numbers in Parts C and D of the table, and in plotting the positions of the points in the various diagrams given in the text.

	Specimen No.				
	46AC36	46AC158	46AC48	46AC97	46AC260
SiO_2	48.39	51.49	50.81	55.05	59.62
Na_2O	2.74	3.22	3.12	3.38	3.10
K_2O	0.98	1.16	1.34	1.23	0.95

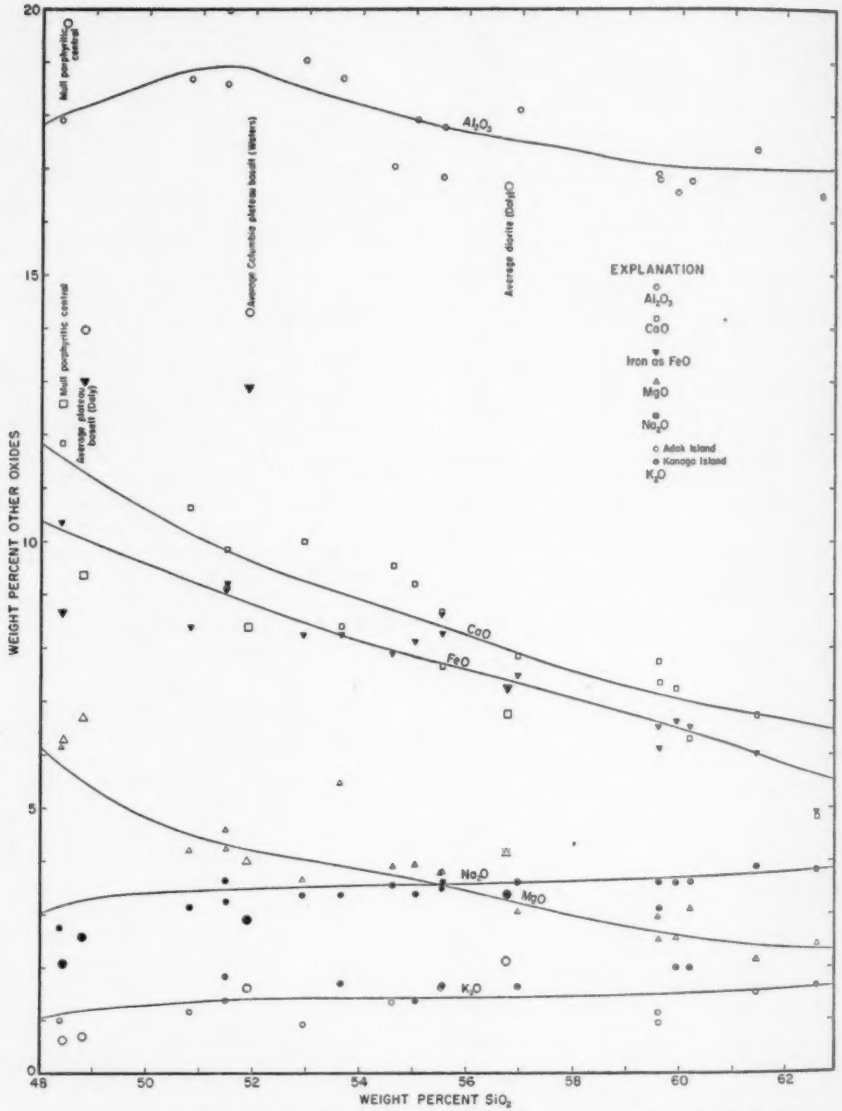

FIGURE 2.—VARIATION DIAGRAM FOR VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

The values for the several oxides in the Adak and Kanaga analyses have been compared with the variation diagrams for Katmai (Fenner, 1926b, p. 700) and with those for Okmok caldera, on Umnak Island. In the plot of the analyses of rocks from Adak and Kanaga as compared with those from Katmai, the aluminum curve is higher at the basic end and rises more sharply, and calcium is consistently higher. As compared with Okmok, the rocks of Adak and Kanaga have a slightly higher alkali-lime index, and lower content of alkalies.

Variation diagrams for a number of Cascade and adjacent volcanoes have been compared by Williams (1935, p. 296–298). The differences of the diagrams for the rocks of Adak and Kanaga from those presented by Williams are comparable to the differences within the latter group. In the Aleutian analyses, alumina reaches a higher maximum than in any of the lavas from the Cascades, except Crater Lake, whose lava is also similar in the pronounced character of the maximum. The curve for iron resembles most closely, in course and position, that for iron in the rocks of Medicine Lake. Magnesia in the rocks of the Aleutian Islands is lower than in the High Cascade volcanoes, and the trend resembles most closely that for the Steens Mountain series. The trend for calcium is also like that of the Lassen Peak series, but the values are consistently a bit higher.

To get a clearer expression of the trend of differentiation, and perhaps reduce the scatter of the points, the "position" of the analyses was calculated according to Larsen's system (1938): "MnO is added to FeO, BaO and SrO are added to CaO, and the major oxides, SiO_2, Al_2O_3, FeO plus nine-tenths of Fe_2O_3, MgO, CaO, K_2O and Na_2O are adjusted so that their sum is 100." "Position" is then defined as given by the sum of one-third of SiO_2 and K_2O, minus the sum of MgO, total iron as FeO, and CaO, all as recalculated above (Fig. 3). As compared with the original silica variation diagram, the scatter of points is reduced somewhat, except for alumina. This result, indeed, might have been expected from the mathematical structure of the method of calculation, without regard to the inter-relations produced by the chemistry of the processes of magmatic variation; i. e., a plot of x, y, z, ... against f(x, y, z. . .) will be, in this situation, where x, y, z, . . . are not strictly independent variables, a smoother curve than a plot of x, y, . . . against z.

To facilitate comparison with Larsen's diagrams (1938, p. 514–515), the ratio of the scales on the axes of abscissas and ordinates is the same as he used. Comparison of the plot for the rocks of Adak and Kanaga with those for the provinces plotted by Larsen confirms the calc-alkaline nature of the Aleutian rocks; certain differences are apparent, however. Iron and sodium resemble in trend and position of curves the corresponding curves for the San Francisco Mountains. The curves for magnesium and calcium are similar in trend to those for other calc-alkaline series, but are respectively lower and higher than any plotted by Larsen. Both silica and potassium have flatter trends than in the other calc-alkaline series plotted by Larsen.

No attempt has been made to utilize the type of triangular diagram suggested by Larsen. The upper diagram of Figure 4 incorporates part of the information furnished by the Larsen triangular diagram—the ratio of Or:Ab:An among the normative feldspars. The clustering of the points shows how little difference in the normative compositions of the feldspar is found in this rock series.

The lower diagram in Figure 4 indicates the compositions of the normative pyroxenes in the volcanic rocks. The line C-D is the two-pyroxene line of Tsuboi (1932, p. 77), considered by him to mark the upper boundary of the field containing points representing rocks with stable phenocrysts of orthorhombic pyroxene. As indicated in Figure 4, all the rocks of Adak and Kanaga are represented by points above the line, although many of them have phenocrysts of orthorhombic pyroxene. In many rocks, some but not all of the hypersthene phenocrysts have jackets of augite. It is hardly to be expected that plots of normative molecules will express accurately the distribution of modal minerals. One of several causes of discrepancy is that the positions of many of the points have been displaced to the left by oxidation of the rocks which uses up the available ferrous oxide to form normative hematite, and thus simultaneously releases silica either to form normative quartz or to diminish the amount of normative olivine.

Poldervaart (1949, p. 177–188) has recently employed three methods of graphic representation for the study of Bushveldt and Karroo analyses. One type of triangular diagram is especially useful for showing contrasts in the trends of variation between the calc-alkaline series and the basaltic series which show iron enrichment in intermediate members. In this diagram the three variables are the weight percentages, recalculated to 100, of MgO, FeO, and

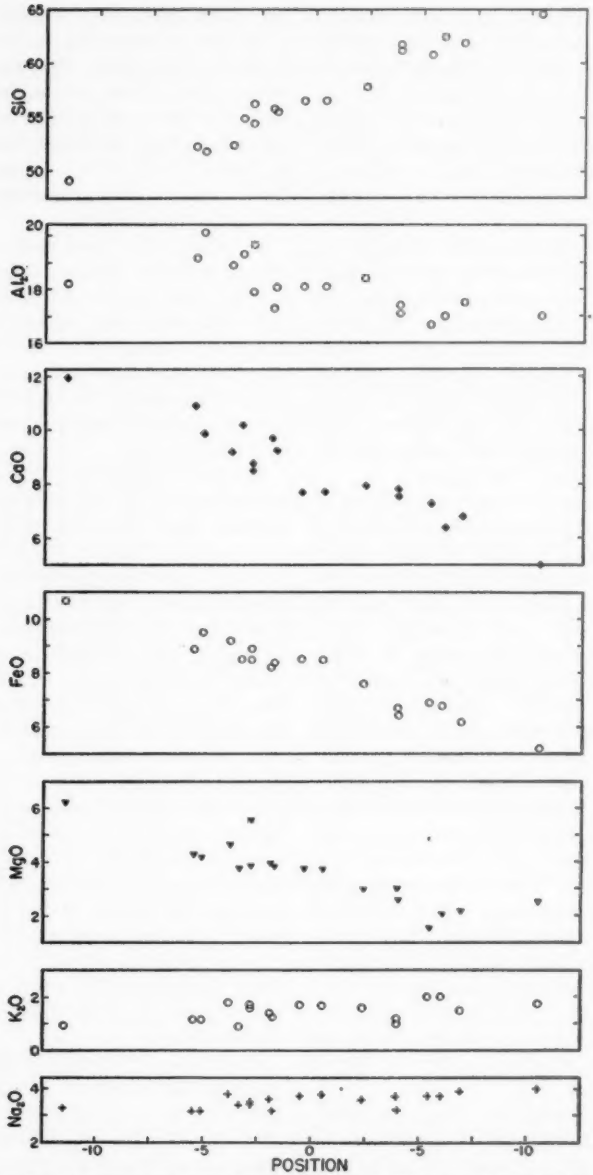

FIGURE 3.—VARIATION OF OXIDES WITH POSITION IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

the sum of the alkalies. Because of the distortion that would be introduced by using FeO only, the diagram used here (Fig. 5) is modified by addition to the FeO of 0.9 of the Fe_2O_3, because the oxidation of some of the rocks has distorted the original relations of ferrous and ferric oxide.

This modification results in crowding the

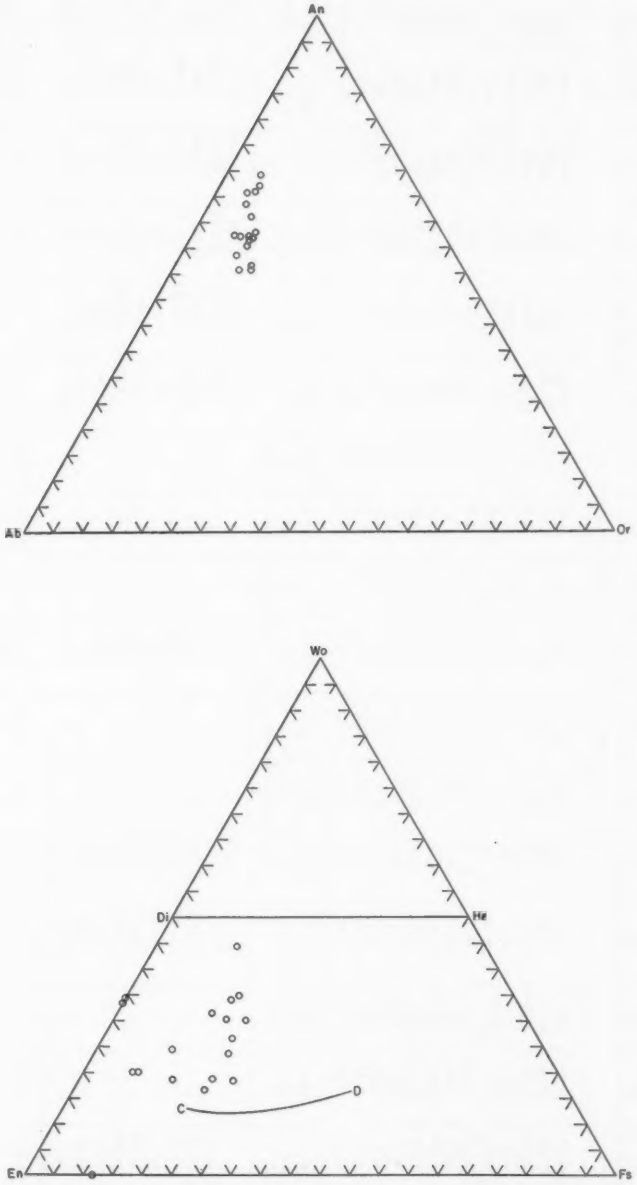

FIGURE 4.—COMPOSITION OF NORMATIVE FELDSPAR AND PYROXENE IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

points toward the FeO corner of the diagram. It might be thought that the inclusion of the ferric oxide from the magnetite would distort the relationships of the other oxides, but this proves not to be the case, as is shown by the position of the several points (shown by crosses)

TABLE 1.—CHEMICAL COMPOSITION AND PARAMETERS OF VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS[1]

(All specimen numbers prefixed 46AC; 46AC130 analysed by A. C. Vlisidis, U. S. Geological Survey, except for alkalies, which were determined by W. W. Brannock.)

	Specimen No.																
	36	158	48	135	21	127	174	97	116	275	112	260	13	107	124	175	130
A. Major constituents (Analyst, W. W. Hommel, Ledoux & Co.)																	
SiO_2	48.03	50.16	50.59	51.49	52.95	53.65	54.62	55.04	55.53	55.57	56.97	58.86	59.61	59.94	60.19	61.46	62.61
Al_2O_3	17.90	19.98	18.69	18.58	19.03	17.68	17.04	17.92	16.85	17.77	18.10	16.78	16.89	16.54	16.76	17.35	16.50
Fe_2O_3	4.48	3.89	4.03	3.86	8.18	3.96	3.47	3.07	4.07	3.86	4.15	3.93	6.29	2.96	4.15	3.72	2.90
FeO	6.30	5.70	4.76	5.60	0.87	4.57	4.76	5.34	4.95	4.76	3.73	2.57	0.84	3.96	2.77	2.64	2.31
MgO	6.13	4.21	4.19	4.59	3.66	5.51	3.90	3.94	3.78	3.81	3.05	2.53	2.96	2.57	3.10	2.16	2.46
CaO	11.83	9.84	10.62	9.11	10.01	8.39	9.53	9.20	8.64	7.64	7.83	7.33	7.73	7.22	6.28	6.73	4.82
Na_2O	2.98	3.68	3.57	3.65	3.35	3.38	3.55	2.60	3.50	3.61	3.63	3.52	3.61	3.59	3.60	3.88	3.82
K_2O	1.00	1.46	1.32	1.84	0.92	1.71	1.35	1.50	1.64	1.67	1.64	1.17	1.15	2.05	2.04	1.53	1.66
H_2O+	0.04	0.15	none	0.26	0.10	0.24	0.13	0.22	0.21	0.25	0.20	0.88	0.07	0.09	0.19	0.19	1.68
H_2O-	0.10	0.08	0.02	0.39	0.10	0.22	0.11	0.03	0.04	0.30	0.08	1.39	0.19	0.05	0.17	0.04	0.31
TiO_2	0.92	0.68	0.92	0.72	0.56	0.68	0.84	1.00	0.84	0.68	0.64	0.40	0.48	0.72	0.48	0.38	0.68
P_2O_5	0.30	0.43	0.24	0.32	0.31	0.42	0.26	0.27	0.28	0.34	0.46	0.36	0.23	0.25	0.38	0.32	0.31
MnO	0.17	0.18	0.18	0.18	0.18	0.18	0.15	0.17	0.17	0.18	0.18	0.16	0.14	0.16	0.16	0.16	0.17
Total	100.18	100.44	99.13	100.59	100.22	100.59	99.71	100.30	100.50	100.44	100.66	99.88	100.19	100.10	100.27	100.56	100.23[2]
B. Spectrographic analyses for minor elements (By K. J. Murata)																	
Cu	0.003			0.009	0.004			0.006				0.003	0.002	0.002	0.003	0.001	0.008
Ni	0.0018			0.002	0.008			0.001				0.0009	0.0009	0.000X	0.001	0.0008	0.006
Co	0.002			0.002	0.001			0.001				0.001	0.001	0.001	0.0009	0.001	0.001
Cr	0.002			0.0008	0.0004			0.001				0.001	0.0008	0.0007	0.001	0.0004	—
V	0.02			0.03	0.02			0.02				0.01	0.009	0.01	0.01	0.01	0.008
Zr	0.004			0.006	0.004			0.005				0.004	0.004	0.007	0.006	0.005	0.01
Ga	0.0009			0.0009	0.001			0.0007				0.0007	0.0009	0.0006	0.0007	0.0007	0.002
Ba	0.03			0.05	0.02			0.04				0.03	0.03	0.05	0.06	0.03	0.08
Sr	0.08			0.04	0.08			0.03				0.1	0.07	0.03	0.03	0.08	0.08
B	n.f.			n.f.	n.f.			0.003				n.f.	n.f.	0.003	0.003	n.f.	0.003
Looked for but not found: La, Pb, Be, Ag, In, Cd, As, Sb, Sn, Ge, In, Tl, Mo.†																	
C. Norms																	
Quartz		1.05	1.80		6.85	2.84	5.26	6.01	6.81	6.76	9.96	20.05	16.15	13.26	14.84	16.95	20.97
Orthoclase	5.79	7.29	6.85	10.85	5.45	10.13	7.95	7.90	9.68	9.85	9.68	5.63	6.23	12.13	12.06	9.02	9.79
Albite	23.17	27.21	26.37	30.88	28.37	28.58	30.04	28.57	29.62	30.51	30.72	26.22	30.51	30.25	30.46	32.82	31.46
Anorthite	33.66	36.44	33.58	28.90	34.19	28.01	26.59	29.79	25.42	27.37	28.26	29.07	26.46	22.98	23.53	25.42	22.08
Halite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.18

C. Norms—*Continued*

C. Norms—*Continued*

Orthoclase	5.79	7.29	6.85	10.85	5.45	10.13	7.95	7.90	9.68	9.85	9.08	5.83	6.23	12.13	12.00	9.02	9.79	
Albite	23.17	27.21	26.37	30.88	28.37	28.58	30.04	28.57	29.62	30.51	30.72	26.22	30.51	30.25	30.46	32.82	31.46	
Anorthite	33.66	36.44	33.58	28.90	34.19	28.01	26.59	29.79	25.42	27.37	28.26	29.07	26.46	22.98	23.53	25.42	22.08	
Halite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.18	
Corundum	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5
Wollastonite	9.76	4.01	7.32	5.91	5.61	4.52	7.93	5.88	6.50	3.46	3.14	2.08	4.32	4.67	2.49	2.43	—	
Enstatite	7.82	10.48	10.43	6.76	9.11	13.72	9.71	9.81	9.42	9.49	7.60	6.30	7.37	6.39	7.72	5.38	6.12	
Ferrosilite	3.40	6.46	4.23	3.69	—	4.33	4.78	5.51	4.66	4.76	2.69	1.12	—	3.94	1.17	1.45	1.04	
Forsterite	5.21	—	—	3.27	—	—	—	—	—	—	—	—	—	—	—	—	—	
Fayalite	2.51	—	—	1.97	—	—	—	—	—	—	—	—	—	—	—	—	—	
Magnetite	6.50	5.80	5.83	5.58	1.76	5.74	5.0	4.44	5.91	5.60	6.02	5.69	1.78	4.29	6.02	5.34	4.22	
Hematite	—	—	—	—	6.97	—	—	—	—	—	—	—	5.06	—	—	—	—	
Ilmenite	1.74	1.29	1.74	1.37	1.06	1.29	1.59	2.38	1.59	1.29	1.21	0.76	0.91	1.37	0.91	0.73	1.29	
Apatite	0.71	1.01	0.57	0.77	0.74	1.01	0.61	0.64	0.67	0.81	1.08	0.84	0.54	0.61	0.91	0.77	0.74	
Symbol	$(II)III_{5,4,4}$	$II_{5,*4,4}$	$II_{5,*4,4}$	$II_{5,3*,4}$	$II_{4(5)5,4,4(5)}$	$II_{5,3*,4}$	$II_{*5,3*,4}$	$II_{*5,3(4),4}$	$II_{(4)3,3,4}$	$II_{*5,3*,4}$	$II_{4(5),3*,4}$	$*II_{4,4(3)}$	$II_{4,*4,4*}$	$II_{4*,3,4}$	$II_{4*,3,4}$	$*II_{4,3,4}$	$II_{4,3,4}$	
Name	Auvergnose	Hessose	Hessose	Andose	Hessose	Andose	Andose	Andose	Andose	Andose	Tonalose	Bandose	Bandose	Tonalose	Tonalose	Tonalose	Tonalose	

D. Niggli numbers

al	23.7	29.2	27.8	27.4	29.3	26.7	27.1	28.3	27.1	29.1	30.8	32.6	30.7	30.7	31.3	33.5	35.2	
fm	40.4	35.0	33.9	36.4	32.6	39.0	33.8	34.3	35.5	35.4	31.7	29.7	30.7	29.9	32.3	27.4	28.8	
c	28.5	26.1	28.8	24.4	28.1	23.1	27.5	26.4	25.3	22.8	24.3	25.8	25.6	24.3	21.3	23.6	18.7	
alk	7.4	9.7	9.5	11.8	10.0	11.2	11.6	11.0	12.1	12.7	13.2	11.9	13.0	15.1	15.1	15.5	17.3	
Sum	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
si	108.8	127.5	128.6	128.6	138.3	137.9	147.2	147	151.6	154.8	164.7	196.0	183.8	188.2	194.2	201.3	227.3	
qz	−20.8	−11.3	−9.4	−18.6	−1.7	−6.9	0.9	3.0	6.6	4.0	11.9	48.4	31.8	28.6	33.8	40.3	58.1	
k	0.19	0.201	0.196	0.248	0.154	0.25	0.2	0.21	0.236	0.23	0.23	0.168	0.17	0.27	0.272	0.206	0.222	
mg	0.51	0.445	0.465	0.469	0.437	0.541	0.463	0.46	0.434	0.45	0.42	0.418	0.44	0.40	0.453	0.315	0.461	
Magma-type	Mibaraitic	Belugitic	Belugitic	Leuco-mibaraitic	Belugitic	Orbitic	Belugitic	Leuco-mibaraitic	Pelécitic	Pelécitic	Normal dioritic	Pelécitic	Cumbraitic-normal-quartzdioritic	Normal-quartzdioritic	Normal-quartzdioritic	Normal-quartzdioritic	Normal-quartzdioritic	

* Totals 100.33, after addition of 0.11 Cl and 0.02 F, and subtraction of equivalent (0.03) O.

† 46AC130 contains 0.002 La, 0.01 Pb, and 0.000× Be; Pt, Pd, Bi, and Zn also looked for but not found.

n.f. = not found.

representing the average analyses of basalt, andesite, dacite, and rhyolite (Daly, 1933). The clustering of the points representing the rocks of Adak (circles) and the rocks of Kanaga ($fm_{53.3}$. This has been done in Figure 6 where the analyses of Adak rocks are again represented by circles and of Kanaga rocks by x's. The small range of variation in this group of

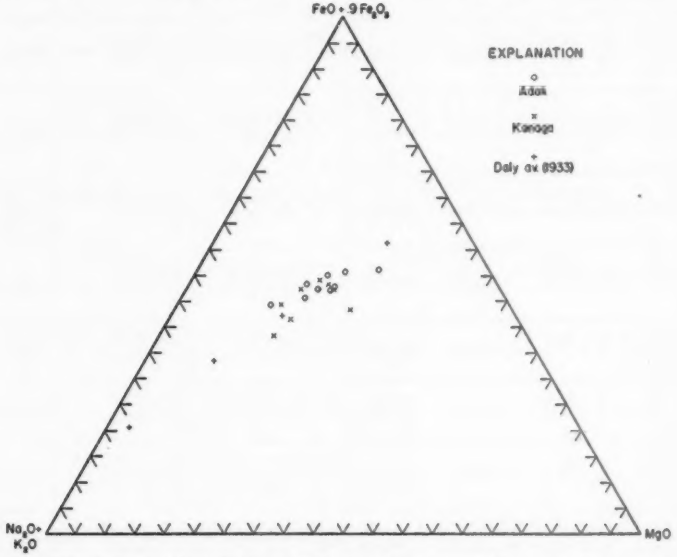

FIGURE 5.—RELATION OF MgO, IRON AS FeO, AND ALKALIES IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

(x) in the interval between basalt and andesite, and principally on the andesite side of the interval, is well shown by this diagram.

The principal Niggli values are shown in part D of Table 1. Niggli (1923, p. 60–620) represented four of these values—al, fm, c, and alk—in a tetrahedron. For plotting on a plane surface, a series of sections through the tetrahedron having the al-alk edge in common, and cutting the c-fm side at the 5, 15, 25, . . . per cent points has been used. On each of these planes, points having a range in ratio c/c + fm of 10 per cent of the total range may be plotted, for example, on Section X, all points from fm_0c_{100} to $fm_{10}c_{90}$. All the Aleutian analyses calculated in this paper have ratios of c/fm from 0.59 to 0.87. The range involved is less than that plotted on a single one of Niggli's sections, but the analyses would actually be divided between two of the standard sections of Niggli—Sections IV and V. For convenience of reference it was thought better to plot all the values on a single diagram, which, if it is so desired, may be thought of as bisecting the region from $c_{37.2}fm_{62.8}$ to $c_{46.7}$-rocks is shown by the close spacing of the points, which fall near the border of Niggli's "Eruptivfeld."

For comparison of analyses from similar petrographic provinces, top and side views of the Niggli tetrahedron were used by Becke (1925) and si was plotted against the right side of the top view. This diagram has been slightly modified by Bacon (1947), chiefly by the use of a different nomenclature. The equivalent terms are:

Becke	*Bacon*	*Niggli*
100-ξ	X	c + fm
η	Y	c + al
ξ	Z	c + alk

Figure 7 shows three Niggli-Becke diagrams, somewhat trimmed to eliminate unused parts of the diagrams. The small diagram in the lower right-hand corner shows the parts of the full diagram used. All component charts of the diagram extend only from X = 0 to X = 80. The XY chart includes Y values from 40 to 70, the XZ chart Z values from 20 to 50; X-k

chart the k-values from 0 to 0.5; and the X-mg chart the mg values from 0 to 0.8. In the lowest chart are plotted the values for analyses of Adak rocks (crosses), Kanaga rocks (stars), Kuriles (Suzuki and Sasa, 1933, p. 2473–2477) (circles), and eight of the principal Niggli magma-types of the Kalkalkalireihe (solid squares) (Burri and Niggli, 1945, p. 31–32). In the middle diagram, a selected group of analyses from Katmai (Fenner, 1926b) have been plotted and the Niggli magma-types have been repeated (half-solid squares), with the designation used by Niggli. The names and designations are:

e. Quartz dioritic magma group
   1. Quartz dioritic
   3. Peléeitic
f. Dioritic magma group
   1. Dioritic
   3. Orbitic
h. Gabbroid magma group
   5. Miharaitic
i. Leucogabbroid magma group
   1. Leucomiharaitic
   3. Cumbraitic
   4. Belugitic

The uppermost diagram shows (as circles) the points for certain selected analyses of rocks from Medicine Lake (Powers, 1932; Anderson, 1941). The three diagrams, taken together, show well the similarities between these petrographic provinces, and the limited range of variation in these Aleutian rocks.

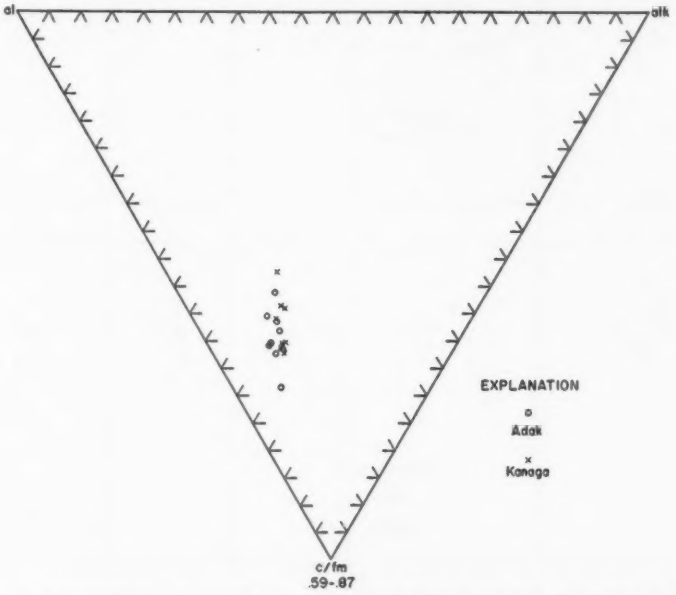

FIGURE 6.—RELATION OF al, alk, c, AND fm IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS
Plotted in a section through the al-alk edge of the Niggli tetrahedron.

The relationships of c, alk, and si are also shown very well in Figure 8, on which points represent the same rock analyses shown in Figure 7. As is well known, this relationship tends to be a reciprocal one; i.e., in calc-alkaline rocks at low values of si the rocks are calcic, and at high values the rocks are soda-rich and lime-poor. If plotted on an arithmetic scale, the points tend to fall on a hyperbolic curve. This suggested that the ratio of c/alk be plotted against si on a logarithmic scale. It was found that the points for all these series tended to group themselves along a straight line, the equation for which is $(c/alk)(si^{2.14}) = 85{,}100$. For purposes of comparison, the points representing the composition of various plagioclase feldspars from Ab_{90} to Ab_{10} have been plotted (as asterisks) on the diagram; they fall along a

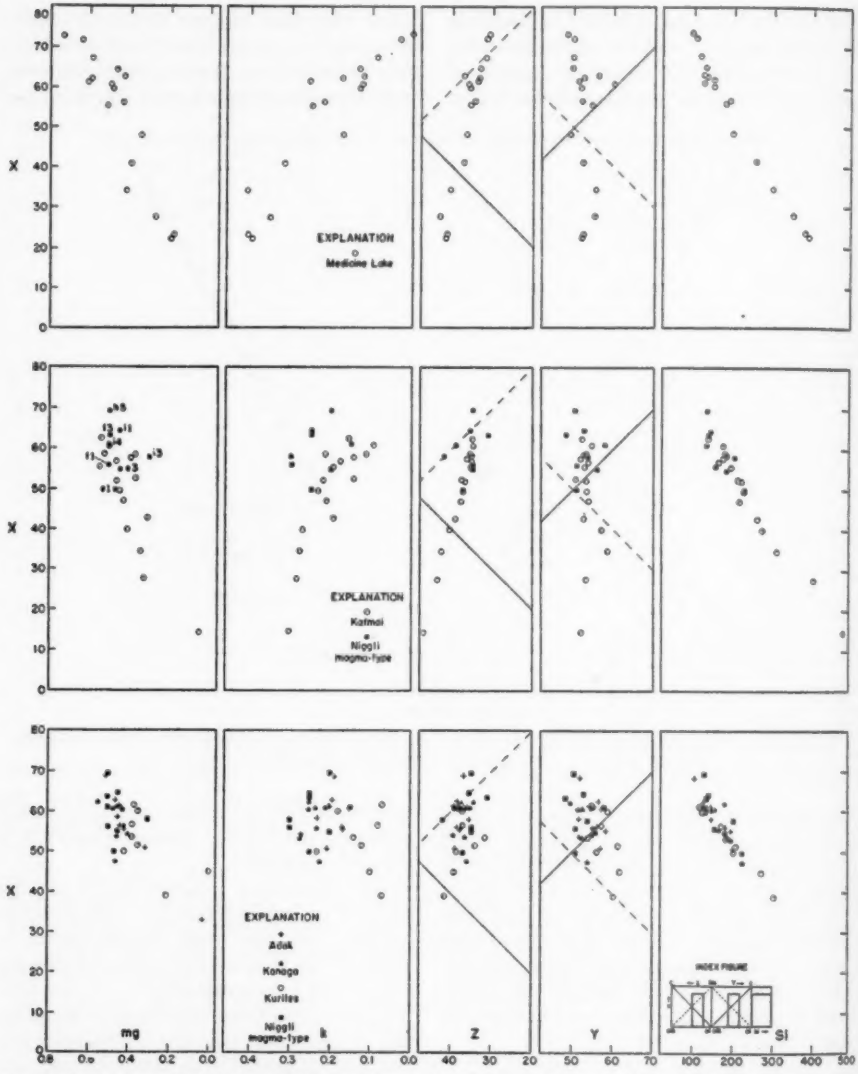

FIGURE 7.—NIGGLI-BECKE PLOTS OF NIGGLI MAGMA-TYPES AND OF ROCKS OF SOME CALC-ALKALINE SERIES

compound curve, which approaches as asymptotes the lines si = 100 and si = 300, and crosses the straight line, the equation of which is given above, almost precisely at the composition $Ab_{50}An_{50}$. The divergence of the general trend from the plagioclase line is caused by opposite effects on the ratio produced by the presence of quartz and of the calcic pyroxenes. In the region where c/alk > 1, lime pyroxene is generally present and causes the points to fall to the left of the plagioclase line. Where the ratio c/alk < 1, feldspars are more sodic than labradorite, and free silica is commonly present in the norm; the points fall to the right of the

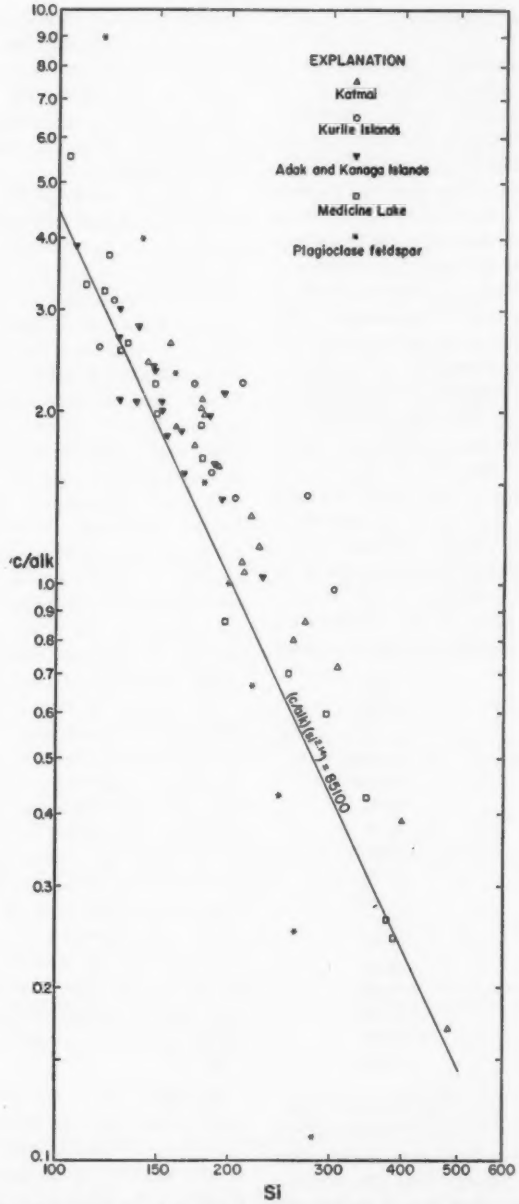

FIGURE 8.—RELATION OF c/alk TO si IN ROCKS OF SOME CALC-ALKALINE SERIES

plagioclase line. Semilogarithmic plots have been used to show the relationship of si to other Niggli values by Tomkeieff (1937), principally to save space.

Minor Constituents

The absolute abundance.—The content of minor elements in some of the rocks, as determined spectrographically by K. J. Murata, is shown in Part B of Table 1. The methods used have been described in a paper by Claffy (1947). Since few of the results are reported to more than one significant figure, they can have, at best, no high order of accuracy. The quantities reported for most of the metals are similar to those found by Sandell and Goldich (1943, p. 182–185) for rocks of similar silica content; noteworthy exceptions among the rocks analyzed by them are those from Minnesota and Michigan, which appear to be exceptionally high in copper. The amounts of zinc, lead, molybdenum, and cadmium reported by them are below the limits of the sensitivity of the method used in this study, hence the report "not found" does not mean that these elements may not be present in amounts comparable with those found by Sandell and Goldich. The limits of sensitivity (K. J. Murata, personal communication) of the spectrographic method used are shown below for the elements listed as looked for, but not found:

La	0.002
B	0.001
Pb	0.001
Be	0.0001
Ag	0.0001
Zn	0.03
Cd	0.01
Pt	0.003
Pd	0.001
Bi	0.002
As	0.1
Sb	0.05
Sn	0.002
Ge	0.001
In	0.003
Tl	0.01
Mo	0.001

The quantities of the minor elements determined in these rocks are roughly equal to those found in similar rocks from Java (van Tongeren, 1938, p. 140), except that the Aleutian rocks are somewhat richer in both barium and strontium than are rocks of corresponding silica-percentage from Java. Comparison with the nickel and cobalt contents reported by van Tongeren is difficult, because of the lower sensitivity of his method, but his averages for NiO, CoO, and Cr_2O_3, embracing all types of magmatic rocks, are much higher than those found in this study. The nickel and cobalt contents found in this study are also less than the averages given by Sandell and Goldich (1943, p. 181).

Abundance in relation to silica content.—The percentages of rare elements, determined spectrographically, in relation to the percentage, by weight, of silica are shown in Figure 9. The scale of the horizontal axis is the same as that used in Figure 2, to facilitate comparison of the curves in the two figures. Kanaga Island is represented by x's; Adak by half-filled triangles. Where circles are used, values showed no relationship to the difference in provenance. The scales used for the several elements (plotted on the vertical axis) differ, one unit on the scales for barium and strontium representing 50 times, and for vanadium, zirconium, and copper 10 times, the amount of one unit on the scale for chromium, cobalt, nickel, and gallium. The several metals are plotted as weight percentages; a chart at the top of the diagram shows the relation of silica percentage to the ratio by weight of strontium to barium.

The content of four of the elements—chromium, cobalt, nickel, and vanadium—varies inversely with the content of silica. Such variation suggests that these elements are associated with the major elements, principally calcium, iron, and magnesium, that show a similar relationship to silica. The noteworthy exception is 46AC130, which is disproportionately rich in three chalcophile elements, Cu, Ni, and Pb. There is a suggestion here that the volatiles which presumably accumulated in the magma to produce the explosion responsible for this tuff may have brought with them several heavy metals, probably as chlorides (Fenner, 1933, p. 88).

As Vogt (1923, p. 307–353) has pointed out, nickel in igneous rocks tends to be concentrated in olivine, and to be found in smaller amounts in the successively younger members of the reaction series. This relation is explained by the similar atomic radii of Ni++ and Mg++. The relations of nickel, cobalt, and vanadium to magnesia are plotted in Figure 10. The fact that results of analyses are generally reported

FIG

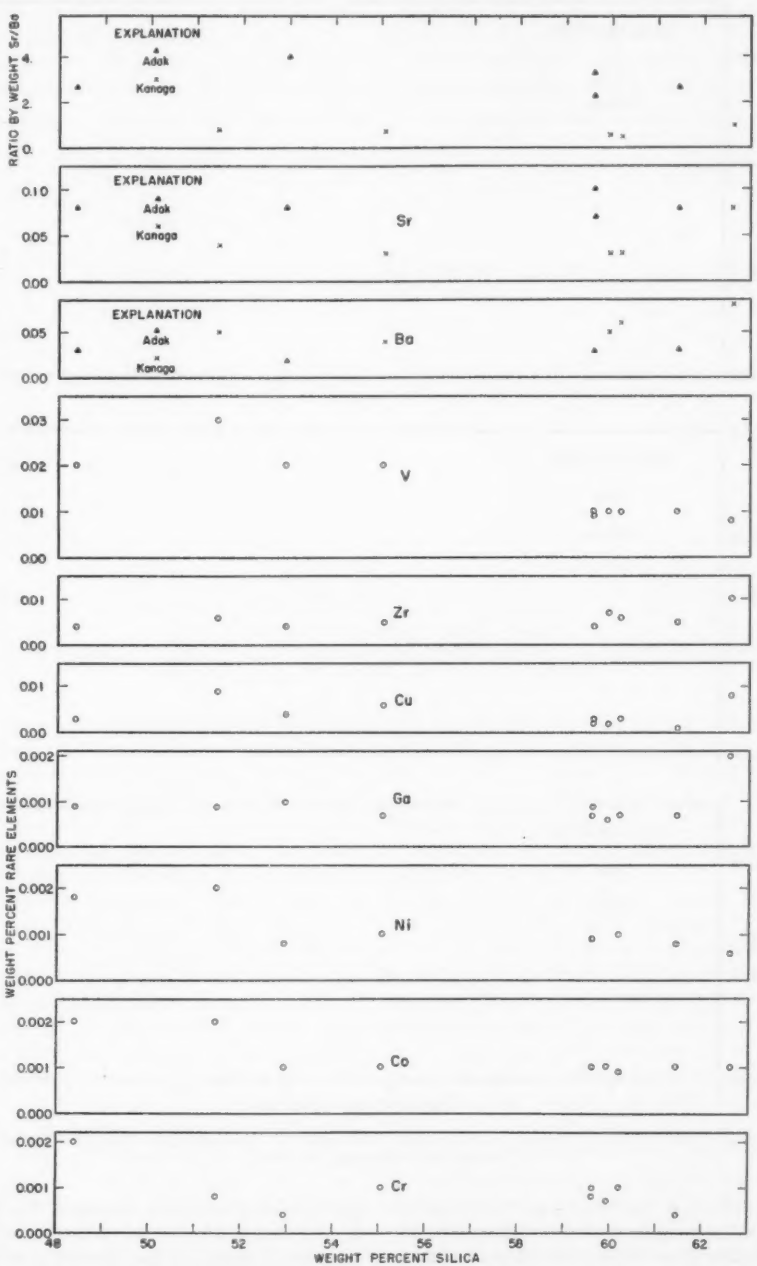

FIGURE 9.—RELATION OF MINOR ELEMENTS TO SILICA CONTENT IN TERTIARY AND QUATERNARY VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

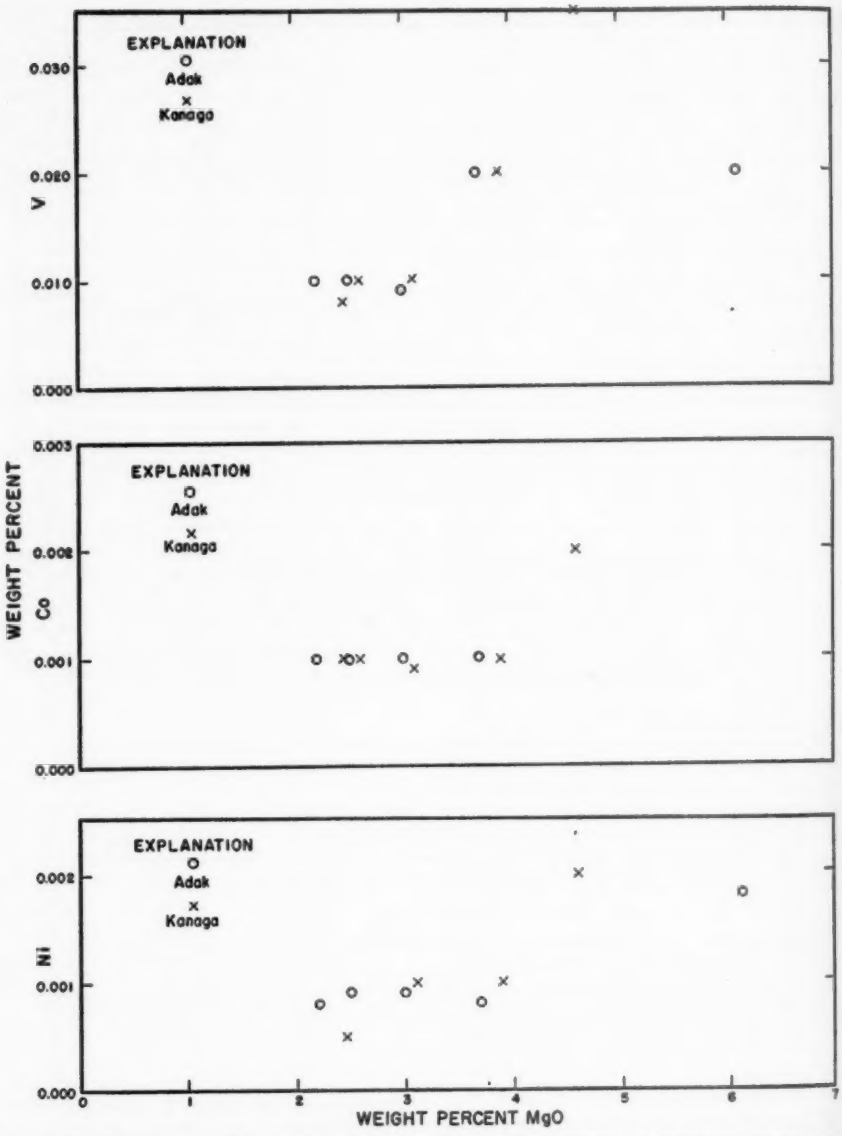

FIGURE 10.—RELATION OF NICKEL, COBALT, AND VANADIUM TO MAGNESIA IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

only to the first significant figure may explain some of the irregularity in distribution of points in this and other figures. Errors in the determination of major constituents may also be, in part, responsible. In this figure, circles indicate Adak rocks; x's indicate Kanaga rocks. About all that can safely be deduced from the distribution of points on the diagram is that the rocks higher in magnesium are also higher in nickel, cobalt, and vanadium. Sandell and Gol-

dich (1943, p. 179) calculate an average ratio of Co to MgO of 0.00066. The values plotted in Figure 10 do not permit the calculation of the corresponding ratio for the Aleutian analyses, but it is obvious that the ratio found by Sandell and Goldich must be about twice as great as that prevailing in the Aleutians. It may be significant that relatively high vanadium contents persist to a content of magnesium lower than that at which the cobalt and nickel content falls off abruptly. This may be a reflection of a tendency for vanadium to be concentrated in clinopyroxene, while cobalt and nickel are concentrated in olivine. Such a tendency was observed by Wager and Mitchell (1945, p. 207–208) in the Skaergaard rocks.

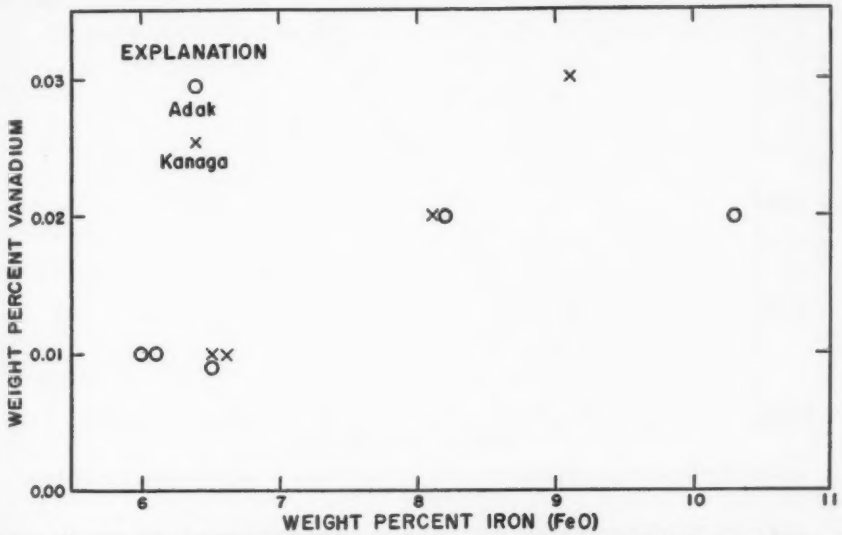

FIGURE 11.—RELATION, IN WEIGHT PER CENT, OF VANADIUM TO IRON, PLOTTED AS FERROUS OXIDE, IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

Relation of vanadium to iron oxide.—Rankama and Sahama (1950, p. 596) have suggested that some, at least, of the vanadium is present in iron oxide minerals as V_2O_3, perhaps as vanadian magnetite. The relations (Fig. 11) do not offer any information that would permit a decision as to whether vanadium is more closely associated with iron or with magnesium, as both oxides show nearly parallel courses of variation. Bray (1942, p. 434) found vanadium concentrated in hornblende, biotite, and magnetite.

Relation of gallium to aluminum.—Goldschmidt (1937, p. 661) has shown the tendency of gallium to become concentrated relative to aluminum in the late differentiates and mother liquors. No such enrichment was found over the range of differentiation of the Skaergaard rocks studied by Wager and Mitchell (1943, p. 289). In the Skaergaard rocks, as in the Aleutian, gallium content shows a small range of variation, and is nearly proportional to the aluminum content (Fig. 12).

The gallium content of the analyzed rocks of Adak and Kanaga Islands ranges from 6 to 10 p.p.m., and appears to be substantially lower than that of basic rocks analyzed fluorimetrically by Sandell (1949, p. 41–2). The gallium-aluminum ratio in the Aleutian rocks is also substantially lower than that in the comparable rocks analyzed by Sandell, ranging from 1 to 0.68×10^{-4}, whereas Sandell found ratios from 8.7 to 1×10^{-4}, the lowest ratio being found in a peridotite. The gallium contents of the Adak and Kanaga rocks is comparable with that of 11 German gabbros (Goldschmidt *et al.*, 1933, quoted in Sandell, 1949).

Nockolds and Mitchell (1948, p. 533) found that the Ga/Al ratio is lower in early plagioclases than in the later. The ratio for the

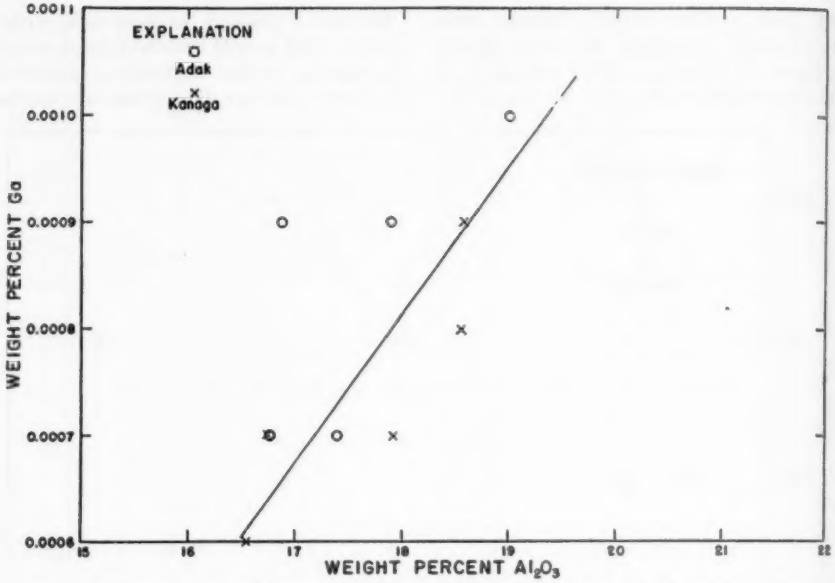

FIGURE 12.—RELATION, IN WEIGHT PER CENT, OF Ga TO Al_2O_3 IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

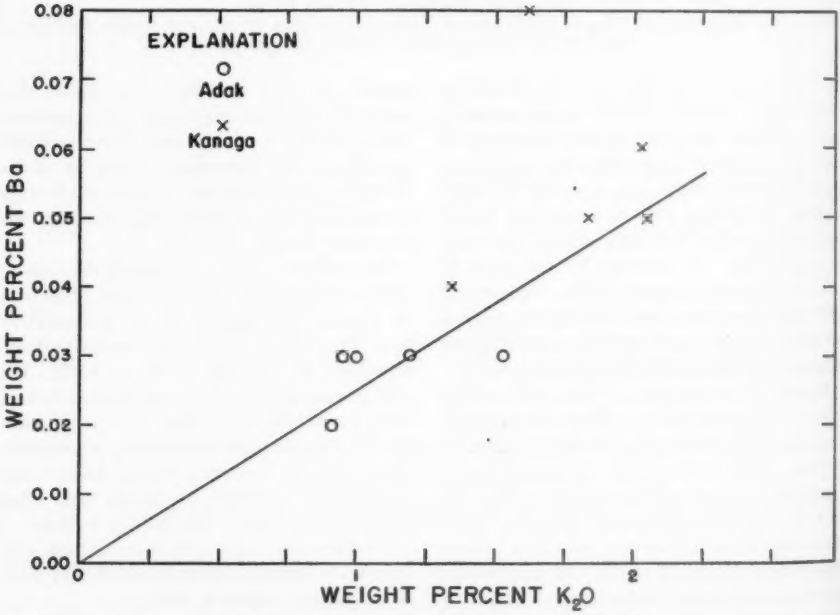

FIGURE 13.—RELATION, IN WEIGHT PER CENT, OF BARIUM TO POTASH IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

analyzed anorthite from Great Sitkin (p. 46), 0.46×10^{-4}, is substantially lower than the value of 1×10^{-4} found in labradorite and andesine by those authors. There is a suggestion here that the low Ga/Al ratio of the Aleutian granite. The relatively high content of barium in the most siliceous rock analyzed (the tuff (47AC130) from Kanaga Island) suggests an incipient enrichment of barium relative to potassium.

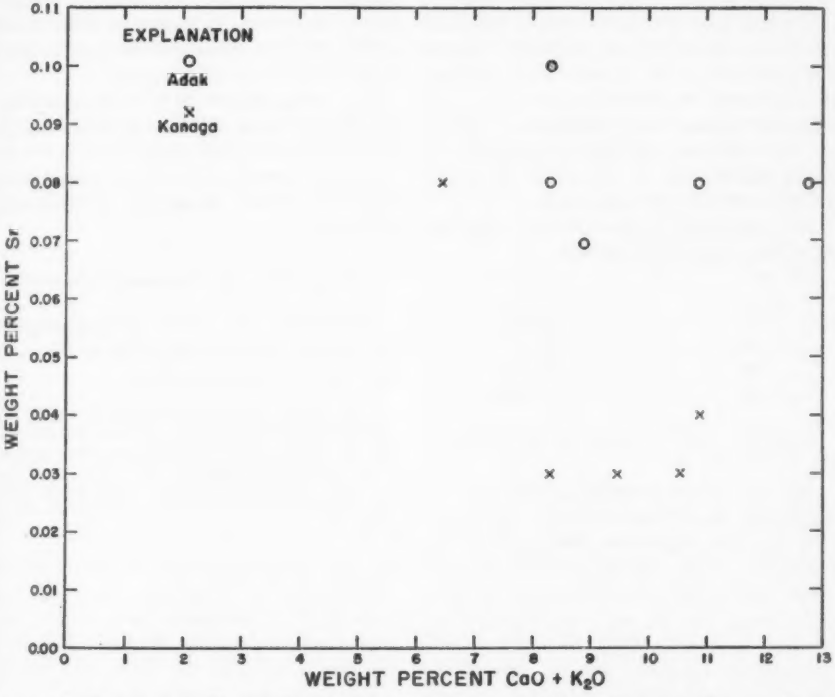

FIGURE 14.—RELATION, IN WEIGHT PER CENT, OF STRONTIUM TO LIME AND POTASH IN VOLCANIC ROCKS FROM ADAK AND KANAGA ISLANDS

rocks is due to a high content of early plagioclase, but the possibility of a lower content of Ga in this part of the earth's crust is not excluded; the differences observed are probably greater than can be accounted for by differences in methods of analysis.

Relation of barium to potassium.—Barium (Fig. 9) shows no relation to silica content, but shows a markedly sympathetic relation to potassium (Fig. 13); and indeed an approximate ratio, applicable to the rocks of both Kanaga and Adak, of $Ba/K_2O = 0.024$ may be computed. This ratio is considerably higher than that in the average gabbro or diorite of Noll (1934), but is comparable to that of the average

Relation of strontium to other elements.—Noll (1934, p. 563–565) has pointed out that the valence of strontium should result in its isomorphous replacement of calcium but that, on the other hand, the relatively great difference in the ionic radii of strontium and calcium and the small difference in those of strontium and potassium should lead to the substitution of strontium for potassium. Because of these relations, Noll (1934, p. 578) has calculated the ratio of strontium to the sum of CaO and K_2O In Figure 14 Sr has been plotted against this sum, but the scattering of points is such that there is no evidence for any dependence of strontium on the other two oxides. What is

evident is that the rocks of Adak (indicated by circles) have a higher strontium content than the rocks of Kanaga.

The results of a spectrographic examination of some very pure anorthite phenocrysts from a recent pumice on Great Sitkin Island suggests that a large part of the strontium in the Aleutian rocks is contained in the plagioclase. Simons and Mathewson (1947, p. 634) have described the pumice and its relations; some of the easily separable phenocrysts of plagioclase collected by me were examined spectrographically by E. L. Hufschmidt, of the U. S. Geological Survey, with the following results:

Minor elements in plagioclase from pumice, Sand Bay, Great Sitkin Island:

Sr	0.07
Ti	0.005
Mn	0.004
Ba	0.001
Ga	0.0009

Looked for but not found: Y, Ag, Cu, V, Zr, Co, Cr, Ni, Pb, B.

The amounts of strontium in the rock as a whole were not determined, but it seems probable that the plagioclase could account for practically all the strontium in the Aleutian rocks. Noteworthy is the relatively low content of barium in this very calcium-rich plagioclase, which is to be expected if the barium is concentrated in potassium feldspar, one of the last minerals to crystallize in rocks of andesitic composition.

Geochemical contrasts between rocks from Adak and Kanaga Islands.—At first sight, the charts for barium, potassium, and strontium suggest that differences in the content of all these metals may be diagnostic of persistent petrographic differences between the rocks from Adak and Kanaga islands. However, the constant relation between potassium and barium, similar in the rocks of both islands, suggests that Kanaga Island belongs to a district with somewhat more than the average amount of potassium, and therefore of barium, rather than to a barium-rich district, and that Adak Island (Figs. 9, 14) belongs to a strontium-rich district. Boron was not found spectrographically in the Adak rocks, but was found in three out of four samples from Kanaga Island. It is well known that barium and strontium are elements whose concentration in the earth's crust ranges widely with geographic position (Holmes and Harwood, 1932, p. 423). Boron is concentrated in marine sediments, and the higher content of boron in the Kanaga rocks suggests either original differences or assimilation of sediments. It is also an element that displays regional variations in abundance (Rankama and Sahama, 1950, p. 485).

The barium content of the Kanaga rocks is but slightly higher than the world average for rocks of similar bulk composition; even the strontium content of the Adak rocks is less than that of rocks from many strontium-rich provinces.

Petrographic and Geochemical Provinces

General discussion.—Long ago Judd proposed the concept of the petrographic province, defined as an area within which:

> "The rocks erupted during any particular geologic period present certain well-marked peculiarities in mineralogical composition and microscopical structure, serving at once to distinguish them from the rocks belonging to the same general group, which were simultaneously erupted in other petrographical provinces."

In some provinces it has proved possible to delimit areas of smaller size, which may conveniently be termed petrographic subprovinces or petrographic districts. With the decrease in the size of the unit, the distinctions between the units become fainter and fainter.

Now, of course, the criteria for the recognition of petrographic provinces, as well as units of smaller size, are dependent on two principal variable factors: the composition, pressure, and temperature of the magma, and its rate of consolidation. What renders the proper assignment of a given igneous rock difficult, in many cases, is that the chemistry of the magma is altered by differentiation, as well as by assimilation, and that the conditions of consolidation of consanguineous rocks may differ widely. The difficulty of assignment is increased by the fact that, although the total number of elements present in an igenous rock in detectable quantity may be 20 or more, the number of separate primary mineral phases recognized by the petrographer in the average igneous rock is commonly less than 10. The petrographer com-

monly calls to his assistance the chemist, and utilizes the chemical analyses of the rocks in two different ways: First, to furnish data by which the course of differentiation in a series of related rocks may be deciphered, and, second, to furnish data by which the rocks of one district, or province, may be compared or contrasted with similar rocks from another district or province. The type of calculation and graphic representation best suited to one purpose may not be suited to the other. Since in most rock-making minerals of igneous rocks, the major metals, except aluminum, play a structural role quite different from that of silicon, the course of differentiation is best displayed by plotting the several oxides against silica, in some form of the usual variation diagram. On the other hand, consanguineous rocks seem to be best discriminated from nonconsanguineous rocks by the use of the ratios between oxides that tend to vary sympathetically in differentiation. In the C.I.P.W. system, the ratio of K_2O' to Na_2O' is used in classes I, II, and III to determine the subrangs; and the ratio of MgO to FeO in Rang 4, classes IV and V. In the Niggli system, k is the ratio of K_2O to total alkalies and mg is the ratio of MgO to the sum of FeO, MgO, and MnO. These ratios are used in discriminating the magma-types. Such ratios, however, are subject to the objection that, while they generally differ somewhat for rock suites of different kindreds and clans, they also change constantly during the differentiation of a single suite, because the amounts of the several oxides entering each of the mineral phases change constantly during the course of differentiation with the changes in the energy relations in the magma.

Resemblances between modes of distribution of major and minor constituents.—The minor constituents of igneous rocks fall into two main groups. The first group, because of valence or ionic size, is excluded from the structures of the common rock-making minerals, and is therefore commonly relegated to the residual magma, where, in many cases, it may become sufficiently concentrated to form independent minerals in the pegmatites. The second group closely resembles one or more of the major constituents and therefore is readily concealed in the crystal structures of the common rock-making minerals. The two species of atoms or ions that are thus capable of readily substituting for each other in a mineral structure are called diadochic, following a suggestion of Niggli. The factors that govern the occurrence of diadochy include the ionic radii, the ionization potential, and the particular crystal structure involved (Rankama and Sahama, 1950, p. 121–127). It is suggested that a particular pair of atoms or ions that may substitute diadochically for one another in a given structure be referred to as a diadochic pair, and that the ratio of the rare to the common constituent be termed the diadochic ratio. Many of the rarer elements may form diadochic pairs with more than one of the commoner elements, the degree of substitution being greater for one element at high temperature and for another at low temperature. Other rare elements may, during most of the course of differentiation, proxy for but a single element. The factors governing incorporation of accessory elements in pegmatite minerals have been reviewed by Holland and Kulp (1949). Many of them will be equally applicable to other igneous rocks.

Regional variations in distribution of minor constituents.—Most of the information available on the distribution of the rarer elements is not sufficiently detailed to permit comparison of the diadochic ratios of specific pairs of elements in the same mineral species from similar environments in different provinces. For instance it is seldom possible to compare the Pb/K ratio in a sanidine from one petrographic province with the same ratio in a sanidine from another province; for the most part we are reduced to comparing the absolute amounts of the rare elements in the rocks of one province with those in rocks of another province. Some evidence of regional variation in relative abundance of the rare elements is now available. Reference has already been made to the work of Holmes and Harwood (1932, p. 423) on the distribution of barium and strontium. Rankama and Sahama (1950, p. 568) report that the hafnium-zirconium ratio in minerals from alkalic rocks is less than that in minerals from calc-alkalic rocks. It seems possible that, since the alkalic rocks are of relatively restricted distribution, this may be an example of a regional variation. Rankama and Sahama (1950, p. 396)

have also pointed out that ancient granites are deficient in rarer elements, as compared to younger granites, and have cited evidence for the regional variations in abundance in the igneous rocks of several elements, among them Li, U, Be, B, W, Mn, Zn, and Ga.

The determination of the abundances of the rarer elements in the volcanic rocks of Adak and Kanaga islands suggests that the rarer elements may vary in abundance not only from region to region, but also from one small area to another. Such areas may be termed geochemical provinces, subprovinces, and districts, depending on their extent. The best criteria for their recognition will prove to be variations in the diadochic ratio of the rarer elements to their protective elements, which they replace in the mineral structures; or, as in the case of Adak and Kanaga, variations in the ratio of two of the closely related rarer elements to each other, such as the barium-strontium ratio. Ideally, such comparisons should be made only between analyses of the same mineral species, of similar gross chemical composition, and representing similar stages of differentiation. For instance, better discrimination may be made between rocks of two areas, if the strontium contents of their plagioclase phenocrysts are compared only if the phenocrysts have about the same anorthite content and the rocks have similar chemical compositions. Such data are obtained with difficulty, however, and much useful information may be gained by comparison of the analyses of rocks of similar chemical gross composition.

Course of Magmatic Differentiation

Introduction

The development of the various rock types analyzed may be described in two stages: first, development of the initial magma type of the analyzed suite from some hypothetical primary magma; and second, development of the several analyzed types as successive differentiation products of an initial type.

First Stage of Differentiation

The nature of the processes inferred during the first stage of magmatic differentiation depends upon the assumed nature of the primary parental magma. Kennedy (1933) suggested that the most probable parent of the calc-alkaline series is a tholeiitic magma type, to which most plateau basalts belong. On Figure 2 there are plotted Daly's average plateau basalt and an average, computed by Aaron Waters (Anderson, 1941, p. 404), for the Miocene Columbia plateau basalts. The noteworthy feature is that, in general, the differences between the least silicic of the Aleutian rocks and average plateau basalt are of the same kind as, but less than, the differences between the Mull porphyritic central magma type and plateau basalt magma. These differences consist chiefly in the presence of less calcium and aluminum and more iron in plateau basalts. The Aleutian rocks, on the other hand, have more sodium and potassium than either the typical porphyritic central basaltic rocks of Mull, or the plateau magma type. A comparison between the normative compositions of the Aleutian basalt and of average plateau basalt (Daly, 1933, p. 448) suggests that the Aleutian basalt has had on the basis of constant mass about 17 per cent of andesine and 5 per cent of orthoclase added and has lost about 10 per cent of hypersthene, 7 per cent of diopside, 2 per cent of ilmenite, and 3 per cent of quartz. If the change is thought of as involving also the addition of olivine, then even more hypersthene must be eliminated. While much of the difference in composition can be explained by the addition of plagioclase and the removal of pyroxene by crystal settling, these processes do not seem to explain all the observed differences. In particular, the differences in content of minor elements shown by rocks, the general trend of whose differentiation was similar, suggest initial differences that are most easily and conveniently explained by assimilation of nonuniform crustal material. Of the minor elements reported, barium and strontium are the two whose distributional peculiarities seem most likely to be explained on the basis of assimilation. Boron also seems to be present in considerable concentrations in the basic igneous rocks and in marine sediments rich in hydrous oxides of aluminum and iron (Sahama, p. 58–68). Von Engelhardt (1936, p. 224–225) has shown that barium also is enriched relative

to strontium in the clayey sediments. In general then, the differences in the content of the rarer elements between the rocks of Adak and Kanaga islands suggests a certain amount of assimilation of sediments in the magma chamber supplying the Kanaga volcanic center. Since there is no known reason why larger volumes of material should be assimilated in the magma chamber under Kanaga than in the one under Adak, the difference may be in the nature of the material assimilated; the crustal material at the level of assimilation may have been largely basaltic under Adak, so that changes due to assimilation would be small. The general resemblances in the course of differentiation could not be expected to persist if there were great differences in bulk composition of material assimilated in large volume, or if there were great differences in total amount of material assimilated, of composition differing greatly from the initial magma. The presence of accidental xenoliths of mica schist in the tuff erupted from Kanaton may be confirmatory evidence of the nature of the magma chamber walls beneath Kanaga. Similar evidence is lacking for Adak, but is not expectable by this hypothesis since accidental basaltic fragments will resemble cognate essential ones.

Summary of Differentiation of the Analyzed Rocks

The most striking feature of the differentiation revealed in Figure 1 is the persistence of relatively large amounts of both aluminum and calcium into the high-silica range. This feature is a consequence of the high percentage of plagioclase found in all the rocks. The cores of some strongly zoned plagioclase crystals are relatively calcic in rocks with as much as 59 per cent silica. It is inferred that the plagioclase crystals remained in suspension while the ferromagnesian minerals were settling out. Relatively large and conspicuous salite crystals are confined to the more basic members of the rock series. It may be noted that the alumina reaches a maximum at a silica content of about 52 per cent, the silica percentage at which hornblende first appears. This relation between the shape of the alumina curve and the appearance of hornblende is like that noted by Bowen (1928, p. 113).

References Cited

Anderson, C. A. (1941) *Volcanoes of the Medicine Lake Highland, California*, Univ. Calif. Pub., Bull. Dept. Geol. Sci., vol. 25, no. 7, p. 347–422.

Bacon, C. S., Jr. (1947) *Applications of the Niggli-Becke projection for rock analyses*, Am. Mineral. vol. 32, p. 257–295.

Becke, F. (1925) *Graphische Darstellung von Gesteinsanalysen*, Tschermak's min. und pet. Mitt., vol. 37, p. 27–46.

Bowen, N. L. (1928) *Evolution of the igneous rocks*, Princeton Univ. Press.

Bray, J. M. (1942) *Minor chemical elements in Tertiary dike rocks of the Front Range, Colorado*, Am. Mineral., vol. 27, p. 425–440.

Burri, Conrad, and Niggli, P. (1945) *Die jungen Eruptivgesteine des mediterranen Orogens.*, Zurich, Schweizer Spiegel Verlag.

Claffy, E. W. (1947) *Spectrochemical analysis of rocks and minerals*, Am. Jour. Sci., vol. 245, p. 35–48.

Daly, R. A. (1933) *Igneous rocks and the depths of the earth*, McGraw-Hill, New York.

Fenner, C. N. (1926a) *Magmatic problems of the Aleutians*, Nat. Res. Council, Bull. 56, p. 124–127.

—— (1926b) *The Katmai magmatic province*, Jour. Geol., vol. 35, no. 7, p. 673–772.

—— (1933) *Pneumatolytic processes in the formation of minerals and ores in Ore deposits of the Western States* (Lindgren vol.), Am. Inst. Min. Metall. Eng. p. 58–105.

George, W. O. (1924) *The relation of the physical properties of natural glasses to their chemical composition*, Jour. Geol., vol. 32, p. 353–372.

Goldschmidt, V. M. (1937) *The principles of the distribution of the chemical elements in minerals and rocks*, Chem. Soc. London, Jour., p. 655–673.

——; Hauptmann, H.; and Peters, C. (1933) *Ueber die Berucksichtigung "seltener" Elementen bei Gesteins-Analysen*, Naturwisse., vol. 21, p. 363.

Hess, H. H. (1941) *Pyroxenes of common mafic magmas*, Am. Mineral., vol. 26, p. 515–535, 573–594.

—— (1949) *Chemical composition and optical properties of common clinopyroxenes*, Pt. I, Am. Mineral., vol. 34, p. 621–666.

Holland, H. D.; and Kulp, J. L. (1949) *The distribution of accessory elements in pegmatites. I. Theory*, Am. Mineral., vol. 34, p. 35–60.

Holmes, A.; and Harwood, H. F. (1932) *Petrology of the volcanic fields east and southeast of Ruwenziro, Uganda*, Geol. Soc. London, Quart. Jour., vol. 88, p. 370–439.

Kennedy, George (1947) *Charts for correlation of optical properties with chemical composition of some common rock-forming minerals*, Am. Mineral., vol. 32, p. 561–575.

Kennedy, W. Q. (1933) *Trends of differentiation in basaltic magmas*, Am. Jour. Sci., vol. 25, p. 239–256.

Köhler, Alexander (1949) *Recent results of investigations on the feldspars*, Jour. Geol., vol. 57, p. 592–599.

Larsen, E. S., Jr. (1938) *Some new variation diagrams for groups of igneous rocks*, Jour. Geol., vol. 46, p. 505–520.

Niggli, P. (1923) *Gesteins-und Mineralprovinzen*, I. Berlin.

Nockolds, S. R.; and Mitchell, R. L. (1948) *The geochemistry of some Caledonian plutonic rocks: A study in the relationship between the major and trace elements of igneous rocks and their minerals*, Royal Soc. Edinburgh, Tr., vol. 61, Pt. II, p. 553.

Noll, W. (1934) *Geochemie des Strontiums*, Chemie der Erde, Bd. 8, Heft 4, p. 507–600.

Peacock, M. A. (1931) *Classification of igneous rock series*, Jour. Geol., vol. 39, p. 54–67.

Poldervaart, Arie (1949) *Three methods of graphic representation of chemical analyses of igneous rocks*, Royal Soc. South Africa, Tr., vol. 32, p. 177–188.

Powers, Howard A. (1932) *The lavas of the Modoc Lava-bed quadrangle, California*, Am. Mineral., vol. 17, no. 7, p. 253–294.

Ranhama, K., and Sahama, Th. G. (1950) *Geochemistry*, Chicago.

Sahama, Th. G. (1945) *Spurenelemente der Gesteine im suedlichen Finnisch-Lappland*, Bull. Comm. Geol. Finland, No. 135.

Sandell, E. B. (1949) *The gallium content of igneous rocks*, Am. Jour. Sci., vol. 247, p. 40–48.

——; and Goldich, Samuel (1943) *The rarer metallic constituents of some American igneous rocks*, Jour. Geol., vol. 51, p. 99–115, 167–189.

Simons, F. S.; and Mathewson, D. E. (1947) *Geology of Great Sitkin Island*, U. S. Geol. Survey, Alaskan Volcano Invest., Rept. no. 2.

Suzuki, J.; and Sasa, Y. (1933) *Volcanic rocks of the northern Tisima Islands*, 5th Pac. Sci. Cong., vol. 3, p. 2473–2477.

Thomas, H. H., and Bailey, E. B. (1924) *Tertiary and post-Tertiary geology of Mull, Loch Aline, and Oban*, Geol. Survey Scotland, Mem.

Tomkeieff, S. I. (1937) *Petrochemistry of the Scottish Carboniferous-Permian igneous rocks*, Bull. Volcanol., ser. 2, tome 1, p. 59–87.

Tsuboi, S. (1932) *On the course of crystallization of pyroxenes from rock magmas*, Japanese Jour. Geol. and Geogr., vol. 10, p. 67–82.

—— (1934) *Some remarks on the petrology of the common volcanic rocks of Japan*, 5th Pac. Sci. Cong., Pr., vol. 3, p. 2271–2273.

Van Tongeren, W. (1938) *On the occurrence of rare elements in the Netherlands East Indies, Contributions to the knowledge of the chemical composition of the earth's crust in the East Indian Archipelago*, II, Amsterdam, p. 122–179.

Vogt, J. H. L. (1923) *Nickel in igneous rocks*, Econ. Geol., vol. 18, p. 307–353.

von Engelhardt, W. (1936) *Die Geochemie des Bariums, Chemie der Erde*, vol. 10, p. 187–226.

von Philipsborn (1933) *Tabellen zur Berechnung von Mineral—und Gesteinsanalysen*, Leipzig, Akad. Verlagsgesellschaft.

Wager, L. R.; and Mitchell, R. L. (1943) *Preliminary observations on the distribution of trace elements in the rocks of the Skaergaard intrusion, Greenland*, Mineral. Mag., vol. 26, p. 283–296.

——; and Mitchell, R. L. (1945) *Distribution of vanadium, chromium, cobalt, and nickel in eruptive rocks*, Nature, vol. 156, p. 207–208.

Williams, Howel (1932) *The history and character of volcanic domes*, Univ. Calif. Pub., Bull. Dept. Geol Sci., vol. 21, no. 5, p. 51–246.

—— (1935) *Newberry volcano of central Oregon*, Geol. Soc. Am., Bull., vol. 46, p. 253–304

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Short Notes

G. ARRHENIUS' ANALYSES OF OCEAN-FLOOR SEDIMENT CORES TAKEN ON THE SWEDISH DEEP-SEA EXPEDITION*

Gustaf Arrhenius, a young Swedish geologist, has been, for the past three years, making chemical and paleontological analyses and subsequent geochronological interpretations of sediment cores taken from the ocean floor in the Eastern Pacific area. A special coring device, the Kullenberg corer, enabled this expedition to take undisturbed cores up to 19 meters long (previous cores were compressed and limited to approximately 3 meters) representing several million years of sedimentation in the deep sea. By analyses of the sediment for concentrations of carbon, carbonate, nitrogen, phosphorus, Radiolaria, diatoms, Foraminifera, and coccoliths it is possible to determine the relative productivity of marine life at any particular geological time. The upwelling of the nutrient-rich deep water of the ocean in the divergences of the Equatorial Current System make these zones particularly suitable for the support of marine life. The movement of these zones over the ages can be followed from the analysis of the sediments. This movement reflects as well the meteorological conditions since prevailing winds determine the ocean currents.

It has been possible to divide the East and Central Pacific into geographical areas characterized by different types of sedimentation as well as to establish the general stratigraphy covering the Pleistocene period. A method has been developed for the absolute dating of the sediment sequences by determining the distribution of C^{14}.

General Program for the Treatment of Sediment Cores

Over 200 cores were taken on this Swedish Deep Sea expedition which traveled around the world through the Atlantic, Pacific, Indian Ocean, and the Mediterranean Sea. When the expedition returned to Sweden in October 1948, the main lines for the investigation were already drawn up and had been discussed with experts in Sweden, Germany, and the U. S. A.

The program given below has been applied in detail to the Eastern Pacific material and to some extent to the rest of the cores. Other regional investigations are carried out by Prof. Hans Pettersson and Dr. Börje Kullenberg (Box 1038, Göteborg 4, Sweden). Prof. Erik Norin (University of Uppsala, Sweden) and Dr. Otto Mellis (Stockholms Högskola, Stockholm) are dealing with special mineralogical and petrological problems. Glauconite formation in some cores from the West African area is being studied by Mrs. Ulla Regnell (University of Lund, Sweden). The investigation of a terrigenous-pelagic sequence of the Western Atlantic valley is under the direction of Prof. Carl Correns (Göttingen, Germany). The stratigraphy of one core from the equatorial part of the Atlantic Ocean is being investigated by Dr. John D. Wiseman (British Museum, London). Biostratigraphical work with the aid of Foraminifera is being carried out by Dr. Wolfgang Schott (Portugal) and Dr. Cameron D. Ovey (British Museum, London) on the Atlantic cores and by Dr. Fred Phleger (Scripps Institution of Oceanography, La Jolla, Calif.) on the Mediterranean, Carribean, and Atlantic material. Mr. William Riedel (Scripps Institution of Oceanography, La Jolla, Calif.) is studying the Radiolaria. Dr. Sture Landergren (Stockholm 50) is making spectrochemical analyses of Atlantic and Pacific sediments at the Geological Survey of Sweden, and analyses of carbonate, humus carbon, nitrogen, and phosphorus on all

* *Editor's Note:* This Short Note, received through the channels of the State Department, the National Academy, and the National Research Council, has been printed as an experiment and does not establish a precedent. It introduces Doctor Arrhenius more widely, it presents in some detail the rather ambitious program of the Swedish Deep Sea Expedition and the project set up within that program by Doctor Arrhenius, and briefly the results of investigation to date. Other material may be received through similar channels from time to time and may be available for publication if the general readers of the Bulletin find it suitable and valuable.

samples are being carried out by Dr. Olof Arrhenius and Mr. Gustaf Arrhenius (Kagghamra, Grödinge, Sweden). Dr. Fritz Koczy and Dr. Nils Gunnar Jerlov (Box 1038, Göteborg, Sweden) are studying sedimentation problems connected with the hydrographical investigations. Dr. Harold C. Urey (University of Chicago) is studying the distribution of oxygen isotopes, and Prof. Willy Dekeyser (Geologisch Instituut, Rozier 6, Ghent, Belgium) the structure of clay minerals.

Arrhenius' Program

The investigations of the Eastern Pacific material are being led by Gustaf Arrhenius and are being carried out mainly at Dr. Olof Arrhenius' laboratories. Associated with this work are Dr. Fritz Brotzen—Foraminifera (Stockholm 50); Dr. R. W. Kolbe—diatoms; and Dr. W. F. Libby—C^{14} (University of Chicago).

The sampling has been carried out so that slices 1.5 cm thick have been cut out on both sides of all layer borders and in homogeneous parts of the columns with a maximum distance of 10 cm between two samples. Owing to the activity of digging animals, undisturbed separation surfaces are fairly rare in deep-sea facies. The Eastern Pacific cores have yielded more than 2000 samples. These are being subjected to the following investigations:

A. Paleontological investigations.
   1. Foraminifera.
      a. Distribution of species of plankton and benthos.
      b. Concentration in the sediment of Foraminifera—greater than 150 micron and 500 micron.
      c. Degree of integrity of Foraminifera (relation between whole and crushed shells).
      d. Size distribution of Foraminifera.
      e. Taxonomic investigations of the benthonic fauna (Brotzen).
      f. Recrystallization of shells.
   2. Radiolaria.
      a. Distribution of taxonomical groups within the sequences.
      b. Concentration in the sediment of Radiolaria—greater than 150 microns.
   3. Diatoms.
      a. Distribution of species (Kolbe).
      b. Size distribution (in collaboration with Kolbe).

B. Chemical investigations.

   Content of carbonates, humus carbon, nitrogen, phosphorus, iron, manganese, titanium, calcium, magnesium, water, dehydration, and adsorption, trace elements by spectral analysis, and distribution of C^{14} to determine absolute age.

C. Physical investigations.
   1. Strength of sediment.
   2. Color and structure—color by comparison with the Ostwald Farbtonleiter and by means of color photography in the scale of 1:1, macrostructure by means of ordinary photography in the scale of 1:8 and by means of detail pictures in color, microstructure is being studied on polished surfaces and on thin section of samples treated with methyl metacrylate manomer which is polymerized after impregnation.
   3. Distribution of minerals including the clay-mineral group.

It is believed that when the investigations mentioned above have been carried out on this material, a reliable basis will exist for petrographical and geochemical considerations, stratigraphical correlations, and general geological interpretations.

Most parts of the Eastern Pacific investigation were completed in 1951. All the results of the Swedish Deep Sea Expedition will be published in a special series of "Göteborgs Kungl. Vetenskaps och Vitterhetssamhälles Handlingar". These investigations are supported by the Swedish Natural Science Research Council and by private donors. The investigation of the biological, hydrographical, physical, and geological material is directed by a board with Dr. Börje Kullenberg as secretary.

Mr. G. Arrhenius, after completing the present analysis in the spring of 1952, will be at the Scripps Institution of Oceanography in La Jolla, California, where he will work on the Western Pacific data.

Mr. Arrhenius' method of investigation has been reported in detail because of the im-

portance of the analysis of long sediment cores in the geochronological interpretation of changes in meterorological and hydrographic conditions.

Results of Investigation

On the basis of the analytical results completed to date the following can be said:

1. The statistical relationships between the various properties investigated and the abnormal deviations have been determined.

2. It has been possible to divide the East and Central Pacific into geographical regions characterized by different types of sedimentation—*e.g.*, areas influenced by terrigenous sedimentation, volcanic, and tectonic disturbances or areas with undisturbed pure pelagic sedimentation.

3. In areas of undisturbed eupelagic sedimentation a general stratigraphy has been established covering the Pleistocene period. The regular changes in the productivity of the surface layer of the ocean, clearly recorded in the deposits, are believed to be caused by changes in the upwelling at the divergences of the Equatorial Current which in turn depend upon the trade winds and circulation of the ocean.

An absolute dating of the sequence from the Pacific area has been determined by a method described in Tellus, vol. 3 no. 4 (with G. Kjellberg and W. F. Libby).

References

1. Reprint, "The Swedish Deep Sea Expedition. The Geological Material and Its Treatment with Special Regard to the Eastern Pacific", by Gustaf Arrhenius; Geol. Fören. Forhandl., Bd. 72, H.2, 1950.
2. Reprint, "Late Cenozoic Climatic Changes as Recorded by the Equatorial Current System", by G. Arrhenius; Tellus, Vol. 2, No. 2, May 1950.
3. Reprint, "Foraminifera and Deep Sea Stratigraphy", by G. Arrhenius; Science Vol. III, No. 2881, March 17, 1950.
4. Reprint, "The Concentration of Nitrogen in Samples of Cores 13, 15 and 16", by G. Arrhenius; Meddelanden Fran Oceanografiska Institutet i Göteborg, 15.
5. Reprint "The Varvity of Glacial Clay. A Study of the Varved Marl in the Uppsala Region", by G. Arrhenius; Arsbok 41 (1947) No. 5, Sveriges Geologiska Undersokning (in Swedish).
6. Reprint, "Carbon and nitrogen in subaquatic sediments", by G. Arrhenius; Geochimica et Cosmochimica Acta, 1950, Vol. 1, pp. 15 to 21. Butterworth—Springer, London.

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AVAILABILITY OF U. S. GEOLOGICAL SURVEY TECHNICAL FILES IN PALEONTOLOGY*

BY MEMBERS OF PALEONTOLOGY AND STRATIGRAPHY BRANCH, U. S. GEOLOGICAL SURVEY

Certain objective technical files of the U. S. Geological Survey's Paleontology and Stratigraphy Branch have been released as Open File Reports, and arrangements have been completed whereby either microfilm or paper facsimile copies may be purchased by interested members of the public at cost of reproduction.

Positive microfilm or paper facsimile copies of the indexes and bibliographies in question may be obtained at the approximate prices listed below, on filing of prepaid order with Mr. Jerome Kilmartin, Chief of the Map Information Office, U. S. Geological Survey, Washington 25, D. C. Checks should be made payable to The Treasurer, U. S. A. The work will be performed by the U. S. Naval Records Management Center on a cooperative repay basis, and it advises that charges are based on current materials and labor costs, and will be subject to change without notice. For this reason the prices outlined below cannot be guaranteed, and subsequent upward revision may be called for.

The available indexes are given no special authorship credit as they represent the product of Survey teamwork over a long period of time. It is further to be noted that no guarantee of their accuracy is made, as they consist primarily of uncritical compilations, in large part brought together by clerical help, and commonly not checked as to accuracy or consistency of usage. On the other hand, these records are extraordinarily useful research tools, in competent professional hands, and they are being made available to the profession at large in recognition of the fact that they have been compiled at public expense and that it is virtually impossible to bring them into shape for publication as critical indexes within the foreseeable future. The available indexes, number of microfilm rolls and images, and prices are as follows:

Compendium of paleobotanical species (28 microfilm rolls; 135,490 images)

1. Duplicate 16 mm. microfilm	$ 56
2. Paper facsimile in continuous roll 5″ wide	1,017
3. Paper facsimile cut to consistent size	1,313

Paleobotanical bibliographical index (5 microfilm rolls; 17,356 images)

1. Duplicate 16 mm. microfilm	$ 10
2. Paper facsimile in continuous roll 5″ wide	181
3. Paper facsimile cut to consistent size	237

Mesozoic species index—North and Central America, including the Caribbean (8 microfilm rolls; 25,459 images)

1. Duplicate 16 mm. microfilm	$ 16
2. Paper facsimile in continuous roll 5″ wide	290
3. Paper facsimile cut to consistent size	378

Mesozoic species index—South America (3 microfilm rolls; 8,345 images)

1. Duplicate 16 mm. microfilm	$ 6
2. Paper facsimile in continuous roll 5″ wide	109
3. Paper facsimile cut to consistent size	141

Cushman catalog of Foraminifera (33 microfilm rolls; 118,967 images)

1. Duplicate 16 mm. microfilm	$ 66
2. Paper facsimile in continuous roll 5″ wide	1,198
3. Paper facsimile cut to consistent size	1,550

The above records will be available at prices listed, or higher, for orders placed up until the end of 1953, unless contract arrangements are sooner terminated by the Navy Department. Meanwhile, the original records and subse-

* Publication authorized by the Director, U. S. Geological Survey.

quent additions to them will remain available to qualified persons in the Survey's offices in the U. S. National Museum, and with the Museum's "Cushman Collection".

Other technical records of the Survey's Paleontology and Stratigraphy Branch on file in its offices at the U. S. National Museum and available for inspection and use by qualified visitors, but not available for duplication and sale, are as follows:

Cenozoic card catalog and bibliographies (incomplete and in revision)	131,400	cards
Carboniferous and Permian synonymy catalog (a subjective index)	18,300	"
Pre-Mississippian bibliographies and faunal index (incomplete and in revision)	15,000	"
Diatom species index	40,000	"
Ostracode species index	6,000	"
Conodont synonymy index (a subjective index)	5,200	"